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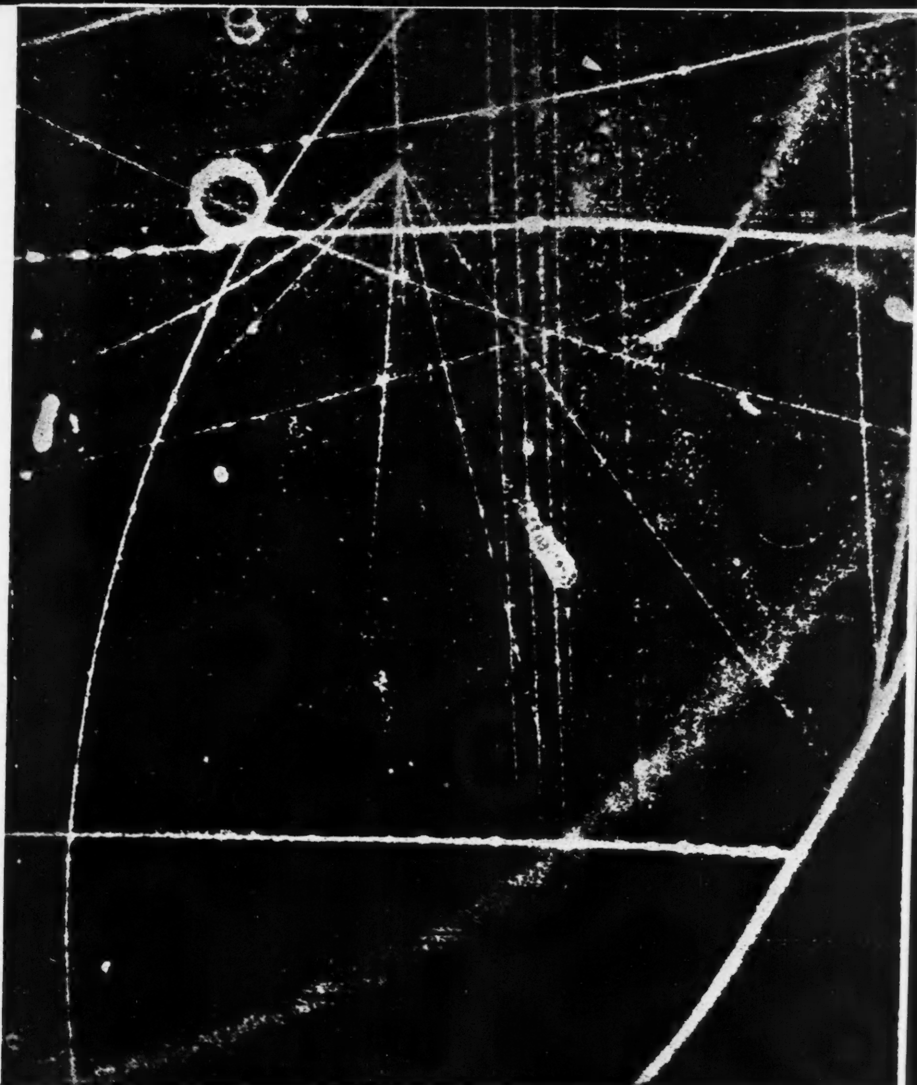

The pattern of radiating tracks (*top left*) represents a nuclear collision giving rise to 4 or 5 mesons. (See Prof. Frisch's article.)

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THE MAGAZINE OF SCIENTIFIC PROGRESS

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NOVEMBER 1955 VOLUME XVI NUMBER 11

THE PROGRESS OF SCIENCE

PARLIAMENT OF ASTRONOMERS

The Ninth General Assembly of the International Astronomical Union met in Dublin from August 29 to September 5. More than 600 astronomers from forty-one nations, accompanied in many cases by their wives, attended the opening ceremony and heard the Prime Minister, John A. Costello, bid the assembly "céad míle fáilte", an Irish phrase which translated into astronomical figures means, "Welcome multiplied by ten to the power of five." And right welcome Eire made the visiting astronomers. Nothing could have exceeded the generosity of the hospitality shown by many official bodies and by individuals to the delegates with their badges, miniature replicas of an ancient Irish symbol of the sun. Not to be outdone, Northern Ireland fêted them on one day when they were brought by special train across the border.

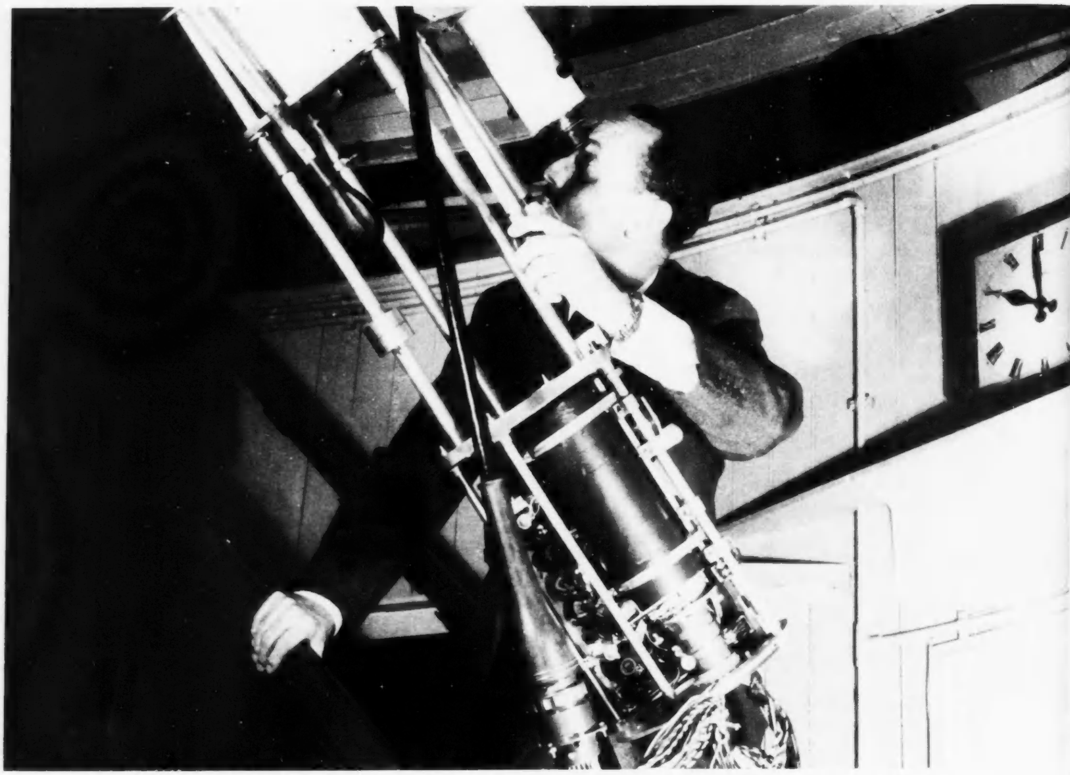
Amid these junketings much serious work was accomplished. Prof. Otto Struve chose the functions of the union as the topic for his presidential address at the ceremonial opening. These functions require some explanation. The Union is not primarily a body to which new discoveries are announced, or a publishing body for scientific papers. *Par excellence* astronomy is the science which needs international co-operation. Magnitude systems in the northern sky must be standardised and compared with those in the south: catalogues of star positions must be inter-compared and scrutinised for errors; stars of known velocity in the line of sight must be selected and recommended for test of the performance of spectroscopes. These are only three of many problems which might be quoted. The Union operates through a series of Commissions, now numbering forty-two, each composed of specialists in a particular field who co-operate voluntarily to foster astronomical research in that field. In the past this organisation has worked well, so well that success has become a little embarrassing. Commissions have tended to become too numerous and too large for fruitful discussion, and resolutions were adopted making minor modifications in organisation.

For many delegates the private discussions which went on almost round the clock between colleagues, previously known perhaps only by name, were quite as valuable as the formal sessions. So numerous were the commission meetings and symposia that a delegation of half a dozen, sharing out attendances, would have been needed to provide the pooled reports essential to a balanced view of what went on. Many delegations far exceeded this number, that from the U.S.A. comprising more than a hundred astronomers.

The assembly contributed its mite to the new spirit of international scientific amity by accepting an invitation extended on behalf of the U.S.S.R. by Prof. Kukarkin to meet in Moscow in 1958 and immediately afterwards provisionally accepted the invitation extended on behalf of the U.S.A. by Prof. Nassau to meet there in 1961.

Some new discoveries did get announced at the meeting. Dr. G. H. Herbig supported the view that T Tauri type stars are very new by demonstrating an instance of their actual appearance in the constellation of Orion. Dr. A. D. Thackeray reported work by himself and his colleagues demonstrating the rotation of the Large Magellanic Cloud about an axis which agreed with that found by the Australian radio astronomers and with that found from a study of the faint outer parts by Dr. G. de Vaucouleurs.

Commissions were conducted on very different lines according to the taste of their presidents. Dr. Walter Baade treated the commission on extra-galactic nebulae to a masterly exposé of the present state of observational cosmology. The commission on variable stars heard much of detail from Prof. Kukarkin on the formulation of the new variable star catalogue and the commission on double stars was similarly occupied with the form of the new combined northern and southern catalogue of these objects.

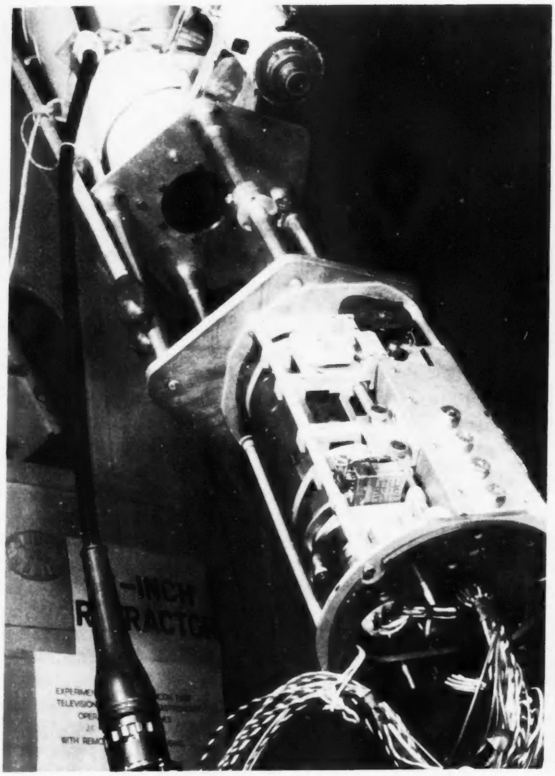


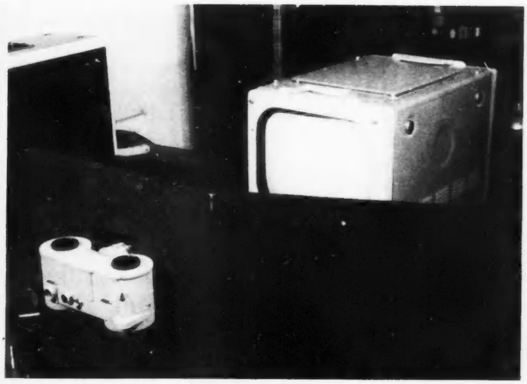
The "electron telescope" in operation during the Dublin congress. This equipment was developed by B. V. Somes-Charlton of Pye's Engineering Research Department, who is a keen amateur astronomer, working in collaboration with Dr. Fellgett of the Cambridge University Observatory. This picture shows, attached to the 12-inch refractor of the Dunsink Observatory, the electronic assembly which converts the telescope image into an electronic pattern. The Moon was obscured by thick cloud during a large part of the Dublin demonstration, but at times when nothing could be seen direct the picture on the TV screen showed the Moon in great detail.

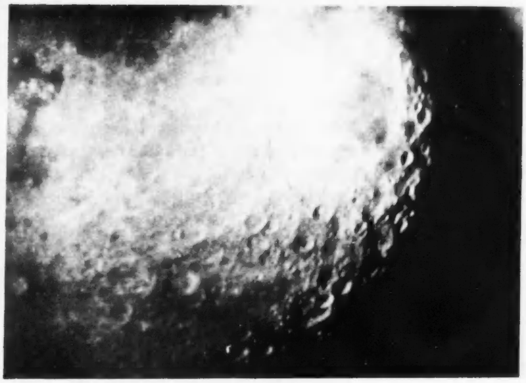
Attendance at commission meetings is not confined to members and many delegates made a special point of attending meetings where they could hear the authors of some of the most interesting and important work in modern astronomy discussing present situations and future developments. Prof. H. C. van der Hulst who predicted the existence of the 21-centimetre radio waves emitted by atomic hydrogen was listened to with the deepest attention for this discovery is being used by the Dutch and other radio astronomers as a powerful tool for the exploration of the galactic system. Dr. W. A. Baum who has carried photoelectric photometry of faint objects with the 200-inch telescope down to unbelievably faint limits was another speaker who held the deep attention of his audience. Dr. A. Blaauw, also originally from Holland, was a notable figure for his discovery, some years ago, of groups of expanding B-type stars (hot blue stars) whose motion demonstrates that stars of this type may be only a few million years old. Another notable figure was Dr. W. Markowitz inventor of the dual-rate camera for lunar photography. This instrument will enable very exact positions of the moon to be determined, and a large number of his cameras will be in use throughout the world during the forthcoming International Geophysical Year.

Difficulty in demarcating the boundaries between related commissions has made the joint-symposia held at I.A.U. meetings very popular and valuable. Classical astronomy of position received its meed of attention at a joint discussion on fundamental stars when speakers from the great fundamental observatories in Germany, England, the U.S.A., the U.S.S.R. and South Africa pooled their experience of the past and their programmes for the future.

An important symposium on the use of photoelectric image tubes attracted much attention. One of the principal speakers was Dr. A. Lallemand, a Frenchman and a leader in the development of the technique. In essence this method depends on the conversion of the image formed by the telescope into an electronic record whose intensity can be amplified by electronic methods before conversion back into a visual record.







(*Left*) A closer view of the electronic assembly (with the casing removed), which includes a supersensitive TV camera image tube. (*Above, top*) With the "electron telescope", it is possible to obtain a visible image of the Moon, for instance, on a television screen. This particular monitor, with a special blue phosphor screen, was used at Dublin to take photographs of the Moon. (*Above, bottom*) Craters on the Moon as recorded by this method. The exposure time for such pictures can be relatively short ($\frac{1}{25}$ second), in contrast to the very long exposure times needed using when taking photographs with purely optical telescope systems.

(We published a note about Lallemand's "electronic telescope" work as long ago as June 1950; the account can be found on pp. 172–3 of that issue.)

The commercial development of television techniques has given a powerful boost to work in this field, and Dr. G. A. Morton of the R.C.A. laboratories at Princeton was there to describe techniques. In spite of difficulties with the weather the demonstrations by Dr. Peter Fellgett (in collaboration with Pye Ltd., Cambridge) of television of the Moon at Dunsink Observatory were sufficiently impressive. Even so, the symposium itself was a little disappointing, for it is clear that much still remains to be done before this technique is used for a serious observational programme. Most exciting of the possibilities raised were, perhaps, Dr. Morton's reference to a new type of receptor surface (the tri-alkali surface) which would have a good red response, and the work on planets. Here there is plenty of light, but short, almost instantaneous, exposures score heavily because blurring due to seeing fluctuations is largely eliminated. The intermediate amplification should enable very short exposure planetary photographs to be taken showing greatly enhanced detail.

As the local Press remarked, this was no "good time" congress. By the end of a full week of meetings nearly everyone had mental indigestion. The commissions had passed their resolutions: the private discussions had resolved many a long-standing difficulty: observers had allowed themselves to be persuaded into undertaking many a programme requested by colleagues from other countries. The delegates dispersed to the ends of the earth for three more years of work until the Moscow meeting.

ELEMENT 43: TECHNETIUM

The periodic system of classifying the elements is now so fundamental to the study of chemistry that it is difficult to believe that less than a century has elapsed since Newlands was ridiculed for putting forward his so-called law of octaves. Yet Newlands was only one step behind Mendeleyev, who put forward the periodic table in substantially its modern form in 1871. Briefly,

Mendeleyev's scheme, and that of Lothar Meyer who independently put forward a similar one at about the same time, depended upon the fact that when the elements were arranged in order of their atomic weights similar properties recurred in individual elements or in groups of elements at intervals of eight—Newlands' octaves. (In modern forms of the periodic table the elements are arranged in order of their nuclear charges, instead of their atomic weights, and this irons out certain anomalies.) Thus the elements lithium, sodium, potassium, rubidium and caesium, whose general properties are strikingly similar, fall within a single group.

But apart from a few obvious anomalies Mendeleyev had a formidable difficulty to overcome. Strict adherence to the sequence of atomic weights would have resulted in some elements falling into groups to which they quite clearly did not belong. With the boldness of genius he asserted that spaces must be left for elements which had still to be discovered. Furthermore, from consideration of the properties of elements adjacent to the empty spaces he predicted in considerable detail the properties of the missing elements. Thus in 1871 he predicted that there must exist an unknown element, eka-silicon, having an atomic weight of about 72 and a density of 5·5; its oxide would have a density of 4·7 and its chloride a density of 1·9. When germanium was discovered in 1886 its values in respect of these properties were 72·6, 5·36, 4·70 and 1·88—an extraordinarily accurate agreement.

Thus a truly remarkable situation arose. Chemists acquired a very considerable knowledge of elements which had never been the subject of a single experiment and which nobody knew where to find. Gradually, however, the missing elements were discovered and the empty spaces in the periodic table grew fewer and fewer.

One space, however, has only very recently been filled. It is that corresponding to the forty-third member of the series of elements, now known as technetium. Mendeleyev himself predicted that there must exist in a sub-group of the halogens an element with an atomic weight of about 100—that now ascribed to technetium is 99—but as there were then several other empty spaces in this part of the table he could say little about its properties. For a great many years the metal eluded discovery. In 1877 Serge Kern announced the isolation from platinum ores of a new metal, which he named davyum in honour of Sir Humphry Davy. But when Mallet in America carried out more thorough experiments with Russian platinum ore concentrates, sent to him from London by George Matthey, davyum proved to be no more than a mixture of iridium and rhodium with a trace of iron. In 1925 Noddak, Tacke and Berg claimed to have established the presence of element 43 (then called masurium) in a variety of minerals by x-ray analysis. But this work seems never to have been accepted as completely conclusive. In the years 1937–9, however, Segré and Perrier showed conclusively that the element did exist in radioactive form and elucidated some of its chemical properties.

In recent years the progress of atomic energy research has opened up a route to the preparation of the element in appreciable quantities. It is obtainable by deuteron bombardment of molybdenum, and it is also a fission product of uranium 235. In 1945 Flagg and Bleidner in America obtained it by electrolysis of molybdenum which had been bombarded with 14 MeV deuterons in the Massachusetts Institute of Technology's cyclotron.

Technetium has an atomic weight of 99, but it exists in at least nineteen isotopic forms, whose half-lives range from a few seconds to hundreds of thousands of years. In the periodic table it lies between rhenium and manganese, resembling the former more closely than the latter.

Spectroscopic evidence indicates that technetium is widely distributed in the earth's crust, though no ores rich in the metal are known. It is in fact present in the earth's crust to the extent of about one part in one thousand million. At first sight this would appear to preclude its use for practical purposes, but it is perhaps significant that its companion element rhenium is equally rare but has nevertheless been commercially available, principally in the form of salts such as perrhenates, since the 1930's. If technetium, too, were available it could be most useful in atomic energy work, for it has a most unusual combination of properties, namely high resistance to corrosion, a high melting-point (2700°C), and a low cross-section for thermal neutrons. These qualities make it eminently suitable as a "canning" material for piles. It is problematical, however, whether technetium can be sufficiently readily obtained for this useful combination of qualities to be exploited.

A substantial paper on the chemical properties of technetium was presented to the Geneva atomic conference by a Russian worker, J. B. Gerlit, who referred to the recent discoveries of the presence of the element in the atmosphere of the Sun and young stars.

AMINO-SUGARS

To the non-scientist the word "sugar" commonly suggests no more than the commercial product that is derived from cane or beet and is used in enormous quantities for sweetening foods. This particular substance, sucrose is, however, no more than a single member of the very large family of sugars, all of which have certain chemical properties in common. Some people may be surprised to realise that sweetness is not one of these; some of the sugars are virtually tasteless. All sugars contain only three elements—carbon, hydrogen and oxygen. The two latter elements are generally present in the same proportion (2:1) as in water; it is for this reason that the sugar derivatives known as carbohydrates are so named. The carbohydrates consist of sugar molecules joined together in long chains—for which reason they are known also as polysaccharides—much as proteins consist of long chains of amino acids. Starch and cellulose are natural carbohydrates of exceptional importance. Starchy foods—such as corn, potatoes and rice—are staple foods for virtually the whole of mankind and their metabolism is the main source of energy in animals; cellulose is the chief structural material of plants and the main food

of herbivorous animals such as cows and sheep. Thus the sugars and the related carbohydrates occupy a position of quite exceptional importance in the economy of nature.

Apart from sugars and carbohydrates of this kind, there exists also a large class of nitrogenous sugars and of corresponding polysaccharides. In recent years much intensive research has been done in this important field, and this is well reviewed in a new book entitled *Biochemistry of the Aminosugars* (by P. W. Kent and M. W. Whitehouse, Butterworths Scientific Publications, 1955, 40*s*.). Although this treatment of the subject requires a good deal of specialist knowledge on the part of the reader, many points of general interest emerge from this volume.

Amino-sugars are widely distributed in nature, although amino-glucose appears to occupy a position comparable with that of glucose in the field of simple carbohydrates. They are found, for example, in skeletal substances, in bacteria, in fungi, and in a variety of biological lubricants. The integument of insects consists largely of the substance known as chitin, which is impregnated with protein; the exoskeletons of molluscs and crustaceans also contain chitin. Chitin consists basically of amino-glucose molecules arranged in chains. The capsules formed by certain bacteria—the function of which is possibly to protect them against the action of enzymes—also contain amino-sugars. (The bacteria that cause tuberculosis and leprosy are examples of capsule-forming organisms.)

Generally speaking, plants do not produce amino-sugars—possibly because of the need to conserve nitrogen which is urgently needed for other purposes—but the fungi and their relatives are an exception to this rule. Thus the important antibiotic streptomycin, produced by *Actinomyces griseus*, contains an amino-sugar as an essential part of its molecule. Another antibiotic, chloramphenicol (chloromycetin), has a structure which is not strictly that of an amino-sugar but is closely related chemically.

From their occurrence in such relatively simple organisms, it is evident that the ability to utilise amino-sugars appeared at an early stage in the evolutionary process; in mammals they play an even more varied role. Of particular interest and significance is their occurrence in the slimy substances which lubricate the moving parts of animals. These include, for example, the fluids which lubricate the movements of eyes and joints, and those which ease the movement of food through the intestines. In this connexion the substance called hyaluronic acid, which was first isolated in 1934, appears to be of paramount importance; its sole amino-sugar constituent seems to be amino-glucose.

Enzymes capable of breaking down hyaluronic acid are widely distributed in nature; they are found, for example, in some pathogenic bacteria, and in the venoms of snakes and bees. These enzymes undoubtedly play a major role in the permeability of tissue, and consequently they come into the picture when resistance to bacterial infection is being considered. They may be identical with, and are certainly closely related to, the "spreading factor" present in testicular extracts and in certain venoms. These enzymes are sometimes used therapeutically to hasten the absorption of subcutaneous injections.

Amino-sugars also play an important role in mammals as cementing agents. Cartilaginous tissue contains the nitrogenous polysaccharide called chondroitin, which is derived primarily from amino-glucose and is found in the form of chondroitin sulphate. (As there are several varieties of chondroitin, it is more correct to speak of chondroitin sulphate in the plural.) The proportion of chondroitin sulphates depends upon the nature of the tissue and its stage of growth; thus the tissue of the adult may differ considerably from that of the embyro or adolescent animal. In some hyaline cartilage (i.e. the transparent form of cartilage) over one-third of the tissue may consist of chondroitin sulphates. Of great interest is the growing evidence that some rheumatoid conditions, and also the ageing and hardening of arteries, result from disturbances in the metabolism of chondroitin sulphates. If this is so, and the fundamental biochemistry of the pathological processes involved can be elucidated, results of far-reaching medical importance may be achieved.

Another field of medicine in which amino-sugars appear to be of major importance is that of the virus diseases, especially influenza. It appears that the first stage in the infection of living cells by a virus involves its interaction with nitrogenous polysaccharides on the cell surfaces. The same effect causes the agglutination of red blood-cells by influenza virus. As the virus can attach itself simultaneously to more than one red cell it is able to link them together in clumps, which are heavy enough to settle rapidly to the bottom of the tube in which the reaction takes place. This effect is used for the typing of influenza virus, which is of great importance in the epidemiology of the disease.

It is evident that the amino-sugars play a part, and often a very important one, in almost every kind of biological activity, and it is scarcely surprising that they are now being so intensively investigated. Equally, however, it is evident that their full significance has yet to be elucidated, but it is certain that further research will throw much light upon the working of living tissue in both health and disease.

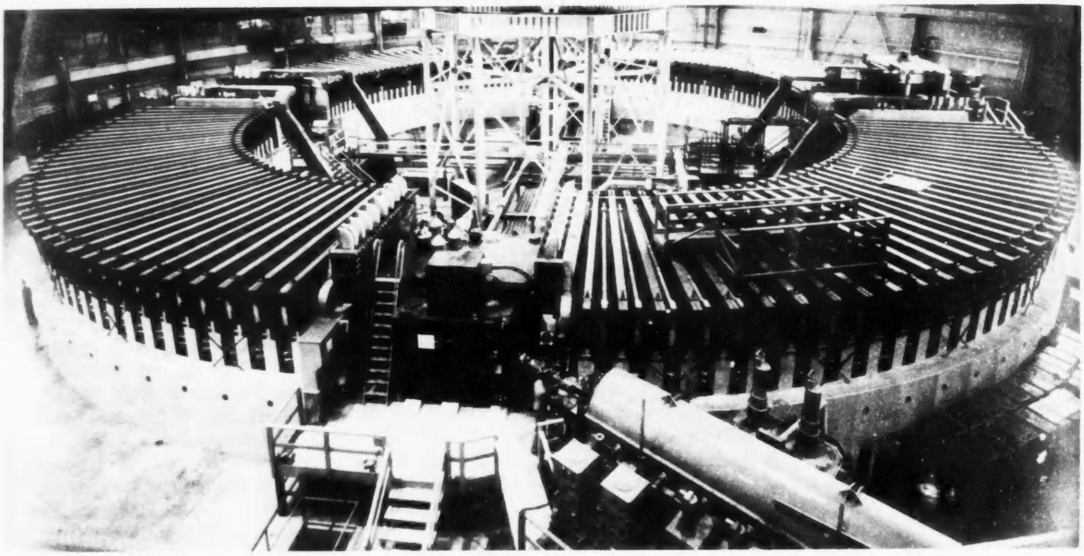


FIG. 1. The Bevatron at the University of California Radiation Laboratory, Berkeley, produces particles of 6 thousand million electron volts. Even more powerful machines are in process of erection, while physicists are engaged in active discussion of the fundamentally new designs required for machines capable of producing particles with energies of a million million electron volts and more. (See also Figs. 6–7.) Proof of the existence of the anti-proton, a discovery announced on October 19, was provided by bombardment experiments with the Bevatron.

HIGH-ENERGY ACCELERATORS: THE SYNCHROTRON

PROF. O. R. FRISCH, F.R.S.

Cavendish Laboratory, University of Cambridge

It was a great achievement in 1932 when Cockcroft and Walton first produced a voltage of 800,000 volts, and the protons accelerated to 800,000 electron volts with its help were considered high-energy particles. They had enough energy to penetrate into light nuclei, and their use led to a rapid advance in our knowledge of nuclear structure. Today that field is not yet exhausted; but it is called *low*-energy nuclear physics, and for pioneering work much higher energies are now needed. The eV—the electron volt, the energy acquired by a particle of electronic charge when accelerated by one volt—has given way to the MeV (million electron volt), and even that unit is getting too small. 6000 MeV (also called 6 GeV, or 6 BeV in the U.S.A.* have been reached, and a gigantic machine designed to accelerate protons to 25 GeV is being built for installation in CERN'S laboratories in Geneva, as was mentioned in DISCOVERY'S feature on that new research centre (August 1955, pp. 332–3). This development has added several new words to the nuclear physicist's vocabulary; the way in which one instrument after another helped us to double the energy every three years, on an average, is illustrated in Fig. 2. But in this article we shall be concerned only with the line of progress which leads from the cyclotron through the synchro-cyclotron to the synchrotron.

The reason for this "armaments race" is found in the tantalisingly small amounts in which Nature provides us with fast particles for the study of atomic nuclei. A typical preparation of radium or polonium delivers many millions of alpha particles (which are fast-moving helium nuclei) per second, but less than one in a million will strike a nucleus in the target presented to them. In studying such nuclear collisions before 1932, days of tedious counting were required to establish a single fact. With a Cockcroft-Walton machine or with a cyclotron, a million times more nuclear bullets can be directed at a target. That made it possible to select particular features for study, greatly increase the accuracy of measurements and still collect data much more rapidly. The enormous advance in our knowledge of nuclear structure in the 1930's was largely due to those early particle accelerators.

However, not much headway was made with the basic problem of nuclear physics: what are the forces acting

* The "B" stands for billion which, of course, is a thousand millions in the U.S.A.; the "G" stands for the prefix "giga" (derived from the Greek "gigas"=giant), which has been proposed for use in Europe, where a billion means a million millions.

between neutrons and protons, the bricks from which nuclei are made? Some rough features of those forces were discovered by firing protons or neutrons of several MeV through hydrogen and studying the collisions which occurred; but it soon became clear that energies of 100 MeV or more would be needed to obtain finer details. But when such energies were first reached about 1947 the results were so puzzling that still higher energies were demanded in the hope of clarification, and that process has not yet come to an end. In addition, entirely new phenomena appear above 300 MeV: mesons (which are charged and uncharged particles heavier than electrons but lighter than protons) are generated (Figs. 6–7). At still higher energy we get hyperons, which are slightly heavier than protons. Many of these phenomena had already been observed in the faint trickle of very energetic particles which Nature provides in the cosmic radiation, and the synchrotron is our latest answer to the demand for much greater numbers of such high-energy particles.

The idea which made it possible to exceed energies corresponding to 10 million volts—at which voltage the insulation difficulties become practically insuperable—was that of *multiple acceleration*. The particles—protons, deuterons, electrons, etc.—are made to pass through a number of successive electrodes, and it is arranged that the voltage is switched on at each gap as the particles pass through but otherwise absent or reversed. In this way the voltage becomes effectively multiplied with the number of gaps. However, a large number of gaps means an apparatus of considerable length and complexity, and it was a truly brilliant idea which enabled E. O. Lawrence in 1932 to make particles pass many times through the same gap between two electrodes in a comparatively small space. The result was the instrument whose name—at first merely a piece of jocular "lab. slang"—has become the trade mark of nuclear physics: the *cyclotron*.

In Lawrence's cyclotron a strong electromagnet with horizontal circular pole faces* forces the particles to move on a curved path, approximately a spiral; as they get faster their orbit automatically expands so that the same time is taken for each turn. If the voltage between the accelerating electrodes—two flat semicircular boxes enclosing the particle orbits—is reversed periodically with just the right frequency (a few million times a second), then each particle which has crossed the gap once at the right time to be accelerated will do so again and again, gaining energy each time and spiralling outward until it reaches the edge of the electrodes (and the magnet).

The cyclotron works very well for "low" energies (up to a few MeV), when the particles have speed much smaller than that of light. But at 10 MeV a proton moves at one-seventh of the speed of light; according to Einstein's theory of relativity its effective mass is then increased by 1%, and so is the time taken for the

* There is no reason why the pole faces should not be vertical, but to my knowledge only one such cyclotron has ever been built.

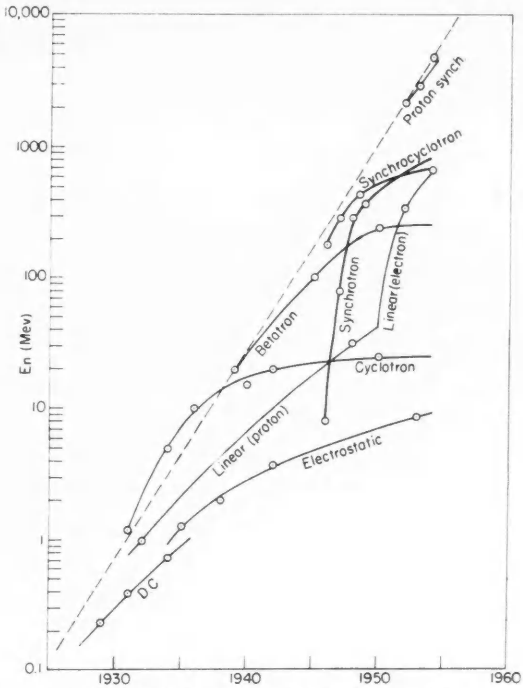


FIG. 2. The rise in energy attained with accelerators during the past 25 years: a logarithmic scale is used for the energy figures.

particle to complete one turn. Consequently after about a hundred turns the protons get seriously out of step, and in order to get the acceleration completed before that happens we need over 50,000 volts across the narrow gap between the electrodes. If more energy were required it would have to be reached in even fewer turns, necessitating a still higher voltage across the gap. With this design of cyclotron an energy of about 12 MeV for protons is about the upper limit; for deuterons (nuclei of heavy hydrogen) the corresponding figure is 24 MeV.

BREAKING THE "RELATIVISTIC BARRIER"

However, Lawrence was not to be daunted, and the "relativistic barrier" was broken in his laboratory at Berkeley, California, in 1945 by the device of *frequency modulation*. The essential principle of this is as follows. As the protons, with increasing energy, take longer to complete a circle, so the frequency of the accelerating field is lowered to keep step with them. After they have reached the target the frequency is raised again, and a fresh troop of protons starts on its spiral journey. Of all the protons emerging from the source at the centre, only one in fifty or so manages to "catch the bus"; but that sacrifice in beam intensity was gladly accepted since it allowed energies of over 100 MeV to be reached.

At present several of those frequency-modulated (f.m.) cyclotrons, or "synchro-cyclotrons" as they are usually

called, are working in the U.S.A. (at Berkeley, Chicago, New York, Rochester and Pittsburgh) with energies of 400–500 MeV. In Britain there is one in Liverpool, where it has recently been found possible to extract a much larger fraction of the protons than has been achieved with other similar machines, to form a narrow external beam. One such machine for 600 MeV is being built in Geneva, and it has recently become known that the U.S.S.R. has been operating one at 700 MeV for some time. Even higher energies would be possible, but then the cost would go up very rapidly. The magnetic field cannot be pushed much beyond 17,000 gauss because of magnetic saturation of the iron,* hence more energy means a larger magnet. As it is, the magnet for the Geneva synchro-cyclotron will cost about £500,000 and for twice the energy one would need a magnet weighing (and presumably costing) four times as much. Financial considerations obviously become very important at this point.

Now in any accelerator which uses a magnetic field to bend the path of the particles one cannot make the orbit at maximum energy smaller than the circle described in a field of 17,000 gauss (the saturation field). Hence a magnet creating a ring-shaped field region of that size is clearly the smallest that can be used. In a cyclotron or synchro-cyclotron, extra weight (and cost) comes from the need to fill also the area within that ring with magnetic field; that is necessary because with a *fixed* magnetic field the orbits must be allowed to grow from a small size. But instead we can let the magnetic field *grow* as the particles gain speed, so that they keep circling on the same, or nearly the same, orbit; then a much cheaper magnet can be used, creating a narrow, ring-shaped magnetic field. The particles are accelerated around a ring-shaped evacuated tube (called the "doughnut") through the action of a radio-frequency field. Such an accelerator is called a "synchrotron".

THE SYNCHROTRON PRINCIPLE

The synchrotron principle was first published in 1945, independently by E. M. McMillan (U.S.A.) and V. Veksler (U.S.S.R.), principally for the acceleration of electrons. But already in 1943 M. L. Oliphant (in an unpublished report) had proposed a *proton* synchrotron, and work on it was started at Birmingham soon after the end of the war. That machine suffered various set-backs and did not come into operation, at its design energy of just under 1 GeV, until 1953. It was the "Cosmotron", begun in 1948 at the Brookhaven National Laboratory, U.S.A., which first passed the 1-GeV mark in 1952, and has been running at its design energy of 3 GeV since 1954. Recently it was overtaken by the "Bevatron" (at Berkeley); the protons of 6 GeV produced by that machine have a speed only 2% below that of light. (Fig. 1.)

The construction of such a machine is a major engineering enterprise which employs a team of fifty scientists and engineers or more for several years, not including the work which is handed over to industrial firms. Well over a year has to be spent in planning and designing the machine, and even then one must allow a large margin of safety for each of those various features which cannot be calculated in advance. The energy to which the protons are to be accelerated determines the diameter of the ring-shaped field region; but first one needs extensive calculations and measurements made on model magnets to decide how close to magnetic saturation it is safe to go. Next one has to decide the width of the doughnut, in which the protons are accelerated. The protons are injected into the doughnut from an auxiliary accelerator and inevitably their directions scatter a little. Since each proton has to circle the doughnut about four million times so that it covers a distance of over 100,000 miles in all, the slightest deviation from the "ideal" direction would cause the proton to strike the wall of the doughnut unless there is a focussing force which drives the proton back towards the ideal path.

Such a focussing force can be provided by making the magnetic field slightly non-uniform, so that it is a few per cent weaker at the outer edge of the doughnut than at the inner edge. The protons will then follow a path which swings in and out and above and below the ideal orbit. One can estimate how wide those swings will be, and having settled what the figures for this factor should be the designers of the Cosmotron decided to make the doughnut 32 inches across and 7 inches from top to bottom. This in turn meant a magnet with pole faces 3 feet wide and 9½ inches apart. To go above 14,000 gauss would have caused the field distribution to become distorted, and in that field protons of 3 GeV would describe an orbit of 30 feet radius. These requirements led to a magnet weighing about 2000 tons and costing over 1·5 million dollars together with its power supply. It is built up in four sections, each in the form of a quarter circle, connected by straight field-free sections which give space for the accelerating field, the injector and much other auxiliary gear. (Figs. 3–5).

POWER FOR THE MAGNET

The power supply for such a magnet presented an interesting problem. For each troop of protons one has to make the magnetic field rise from zero to full value in about one second, which requires a power input of 10,000 kilowatts. However, most of that energy is stored in the magnetic field and might be recovered and used for the next field rise. But how can the energy be stored during the interval? To that problem a surprising solution was found: the energy is stored in a 45-ton flywheel connected to the generator which supplies the magnet current. The whole cycle is as follows. First a large motor (1750 horse-power) brings the generator and flywheel up to full speed. Then a switch (actually a bank of high-current electronic valves known as ignitrons) is closed, current begins to flow through the magnet windings and the field grows while the flywheel slows down

* This limit can be exceeded with air-cored coils (using no iron), but only at prohibitive cost in electric power if continuous operation is required.

a bit. One second later the switch is reversed; the magnet current now flows in reverse through the generator, raising its speed again while the magnetic field returns to zero. At that instant the switch is opened and the magnet rests for a few seconds while the motor brings the generator and flywheel up to full speed, replacing the energy which has been turned into heat in the magnet coils. This "flywheel storage" is used in all the proton synchrotrons that have been built or planned.

While the magnetic field goes up, the protons race around the doughnut, getting faster all the time, and the electric field which accelerates them must alternate more and more rapidly to keep in step with them. Thus frequency modulation is needed again, but—in contrast to the synchro-cyclotron—the frequency in the synchrotron must rise rather than fall during the acceleration. Moreover it must rise in accurate synchronisation with the magnetic field. The time needed by a proton to circle the doughnut in a given magnetic field can be computed: indeed the Cosmotron includes a small electronic computer, connected to a device which measures the magnetic field, and designed to adjust the frequency to its appropriate value at each instant, despite small current variations from one pulse to another. This detail shows the complexity of the whole equipment better perhaps than any other single item.

IMPROVED METHODS OF FOCUSSING

In order to reach still higher energies one might think of simply scaling up the Cosmotron, but that would mean eight times the weight (and presumably cost) for twice the energy. However, a great saving can be achieved by improved focussing whereby the particles are made to swing more closely about the "ideal" orbit; one can then use a narrower doughnut and a magnet with narrower pole faces placed more closely together. Such an improved focussing method became known in 1952; calculations had been done to study the influence of field variations *along* the orbit, and it was found with some surprise that suitable variations could give better focussing. Methods to utilise this new principle were worked out and published by E. Courant, M. S. Livingston and H. Snyder, who must have credit for having brought those ideas into general currency even though N. Christophilos of Athens had laid down the same principles as early as 1950 in a privately printed report which, however, had failed to attract the attention of professional scientists working in this field.

I have said before that focussing, in the Cosmotron for example, is produced by shaping the pole faces so that the magnetic field falls off slightly as one moves away from the centre of the orbits. That procedure drives back those particles which deviate from the ideal orbit either up or down so that they revert to the plane of that orbit after, say, three-quarters of a turn. One might make this "vertical focussing" stronger by further increasing the outward field gradient; but the danger is that then the "horizontal focussing" might be lost, so that particles which deviate from the ideal orbit in a *radial* direction come to spiral out or in until they strike

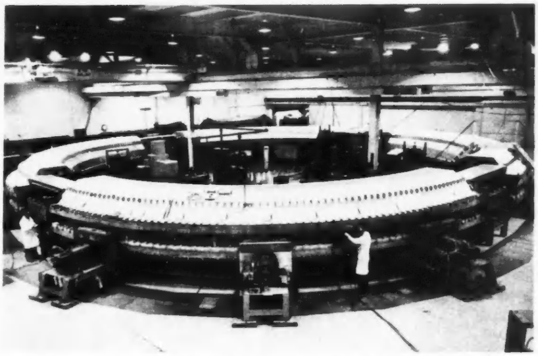


FIG. 3. The Cosmotron at the Brookhaven National Laboratory.

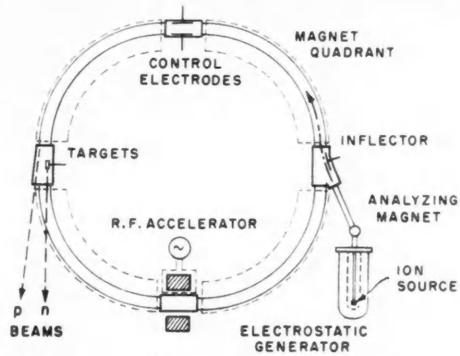


FIG. 4. Plan view of Cosmotron magnet and assembly.

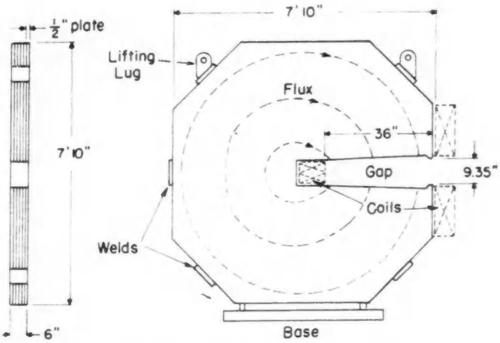


FIG. 5. Cross section through one of the magnet quadrants.

the wall of the doughnut. To put this more quantitatively, let me introduce the so-called *field index*, the percentage decrease of magnetic field for 1% increase of radius. A field index of zero means a uniform field; there is no vertical focussing, but a particle deviating slightly from the ideal orbit while remaining in its plane will describe a circle whose radius is not changed and which will therefore revert to the ideal orbit after about half a turn. The opposite conditions exist for a

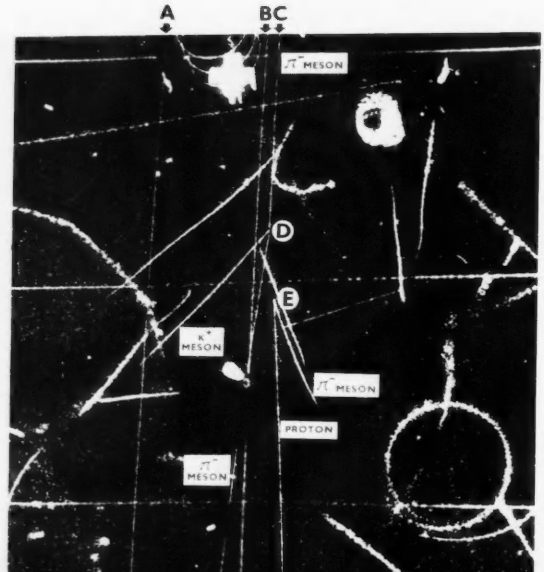


FIG. 6. Mesons produced by the Bevatron. This photograph shows three $\pi-$ mesons of 4·5 BeV passing through a hydrogen-filled cloud chamber. C hits a proton at D and produces a $\kappa\pm$ meson, a $\pi-$ meson and an uncharged hyperon (which travels to E and then decays in flight into a proton and a $\pi-$ meson) and a neutral fragment. (This fragment is invisible and its existence is deduced mathematically.)

field index 1 (that is a 1% decrease of field for a 1% increase of radius). In this case the particles which leave the plane of the ideal orbit revert to it after half a turn, but those which deviate in a radial direction will spiral out or in and are lost. Hence with this focussing system the field index must be made to lie between 0 and 1 if the particles are to stay within the doughnut. Outside those limits we get radial focussing and vertical defocussing for negative field index; vertical focussing and radial defocussing for positive field index greater than 1.

Now the new "strong-focussing" system divides the magnet into a large number of sectors with alternately positive and negative large values of the field index; that is, the field gradient is alternately towards the centre and away from the centre. For that reason one also speaks of alternating-gradient (or A.G.) focussing. A particle will thus be driven alternately towards the ideal orbit and away from it, and the mathematical analysis shows that the restoring force wins by a small margin. That is so because the particle is farther from the ideal orbit—and therefore subjected to a greater force—in those sectors in which the force is towards the ideal orbit than in those where it is away from it. The mathematical analysis shows furthermore that one can in this way achieve much more effective focussing than with the "weak focussing" (field index between 0 and 1). The particles can be made to swing about the ideal orbit several times per turn, and that clearly means much smaller excursions for the same angular deviation. Thus it is possible to use a doughnut and magnet of much smaller cross-section, and hence of much greater length—corresponding to higher energy—for the same cost.

The power of the A.G. focussing method is well illustrated by the plan to build at Geneva a giant proton synchrotron with a doughnut only 4 by 6 inches wide despite its circumference of over 2000 feet. With a total magnet weight only twice that of the Cosmotron it is expected to reach more than eight times its energy; it should accelerate protons to an energy of 25 GeV, that is, to a speed which is only 0·07% less than the speed of light (which no material body can ever reach). One such proton contains enough energy to raise a grain of table salt by an inch; and the same grain, travelling at the speed of those protons, would contain the energy of several hundred tons of high explosive!

More significant to the physicist is the fact that such a fast-moving proton possesses enough energy to create two new protons, one positive and one negative. Negatively charged protons (anti-protons) have never been observed, but their existence is confidently predicted by the theoreticians, and their actual observation would allow us to find out a lot more about the structure of the proton. The Cosmotron does not produce fast enough protons for that, and the Bevatron only just; thus the quest for the negative proton is one of the main incentives in pushing towards higher energies. Of course the cosmic radiation contains particles with much higher energies, and therefore presumably also some negative protons; but none have so far been identified with any certainty, and they are obviously too rare for systematic study.

However, A.G. focussing has also brought new worries; in particular, as I recently read in a technical report, "if accelerator physicists have hearts it is certain that the world 'misalignment' will be found written on them". Because of the strong gradients employed, if one of the magnet sectors is even slightly misplaced the particles will suffer irregular deflection at that point. Even the minutest, but quite inevitable, displacement would be fatal if the particles happened to make an integral number of oscillations per orbit; the extra deflection, recurring at each turn, would cause the oscillations to grow by resonance, and after a few turns all the particles would be lost. The field index must be carefully adjusted to avoid that calamity, and even then

it is necessary to line up the magnet sectors to within about 0·01 inch, an appalling task with some 200 sectors each weighing about 20 tons, forming a circle about twice as large as Stonehenge.

ELECTRON SYNCHROTRONS

A few words about electron synchrotrons. Fast electrons have much less effect on atomic nuclei than fast protons; but for that very reason they can be used to study nuclei in a "non-destructive" manner, for instance in order to discover—from their deflections—how the electric charge is distributed inside a nucleus. Furthermore they can be used to make very narrow beams of extremely short-wave X-rays, whose energy quanta represent convenient packages of pure energy for delivery to atomic nuclei, causing disintegration, meson production, etc. Electrons are less efficient (by a factor of 100 or more) than protons in doing these things, but for various technical reasons much more intense beams can be obtained with electrons, and that partly compensates for their ineffectiveness.

Electron synchrotrons are simpler than proton synchrotrons in that they require no frequency modulation. If the electrons are injected with, say, 2 MeV, they have 98% of the speed of light; any further increase in speed cannot amount to more than 2%, a change which can be taken up by a 2% expansion of the orbit without change of frequency. The first small electron synchrotron was built in Britain by Goward and Barnes in 1946; McMillan's 300-MeV machine was completed in Berkeley in 1947 and was soon followed by several more of similar size (including the one at Glasgow University). But in pushing towards higher energy one meets a new obstacle: radiation loss. An electron on a curved path inevitably loses energy by sending out electromagnetic waves (like a radio transmitter), at a rate which rises steeply with its energy; above 7–8 GeV further acceleration becomes impracticable since it would have to overcome a radiation loss of many MeV for each turn. At 1 GeV the radiation loss is still small, and two electron synchrotrons are operating at about that energy, in Pasadena and in Ithaca, N.Y. (The latter uses A.G. focussing and is the first machine actually to do so.) A much bigger one is being planned jointly by Harvard University and the Massachusetts Institute of Technology; here the protons will be driven along by sixteen radio-frequency generators, each of several kilowatts power, so as to defeat a radiation loss which reaches 7 MeV per turn at the end of the acceleration. To reach still higher energies, electrons would have to be accelerated along a straight line, in a *linear accelerator*, derived from Lawrence's very first attempts at multiple-gap acceleration.

What of the future? will energies go up higher still? I am inclined to say no. The 25-GeV proton synchrotron which is being built at Geneva by CERN, and a similar one being planned at Brookhaven, are not likely to be superseded for some time. At least not in energy; but great efforts are being made, in particular by eight American universities who have combined to form the

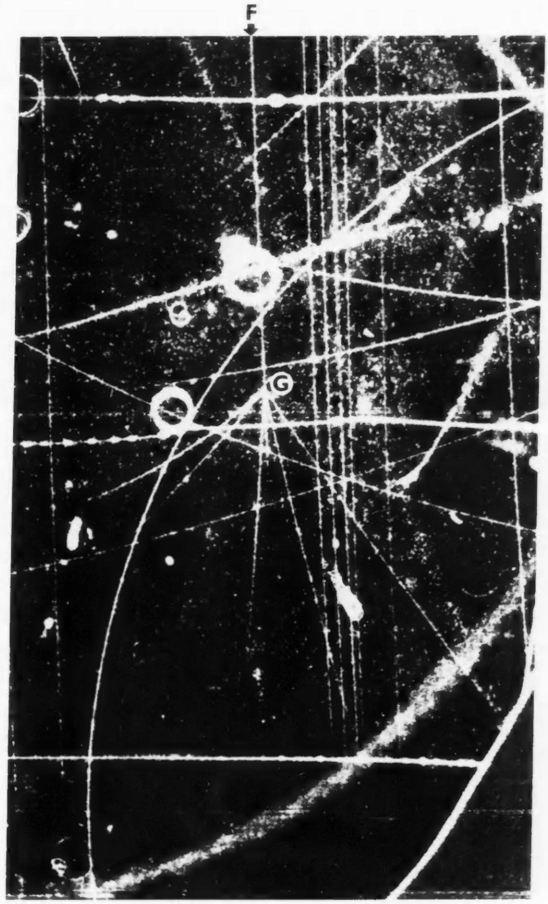


FIG. 7. Another cloud chamber photograph resulting from work with the Bevatron. In this picture a 4·5 BeV $\pi-$ meson (which moves along the track FG) collides with a proton and produces a six-prong event. At least four new mesons have resulted from the collision, possibly five.

Midwestern Universities' Research Association (MURA), to design accelerators for the production of much more intense beams. Several interesting new schemes have been proposed for combining the cheapness of a ring-shaped magnet with the high beam intensity of a cyclotron; the magic letters FFAG (which stand for "Fixed magnetic Field with Alternating-Gradient focussing") represent exciting new possibilities for the more efficient study of very rare meson and hyperon phenomena. But it will still be a year or two before those ideas crystallise into well-defined plans.

(The three diagrams, Figs. 2, 4 and 5, are taken from *High-Energy Accelerators* by M. S. Livingston. This book, published in 1954 by Interscience Publishers, can be recommended to readers interested in obtaining further information on this subject.)

Two major tests of British atomic weapons will take place next year. Sir William Penney (facing the camera in this photograph) will direct the second of these, to be held at the new proving ground at Maralinga in the Central Australian desert. The other is planned to take place in April in the Monte Bello islands, under the direction of Mr. C. A. Adams, who is chief of research at the Atomic Weapons Research Establishment at Aldermaston. These two men were jointly responsible for the scientific side of both the 1952 Monte Bello tests and the 1953 Emu atomic tests; this picture of Mr. Adams (wearing beret) and Penney was taken at Emu.

SIR WILLIAM PENNEY

CHAPMAN PINCHER

At the age of forty-six Sir William Penney is already something of a legend. No one is quicker than he is to point out that the achievements for which he is so often given credit are really the work of a large team. Nevertheless he dominates the field of atomic weapons so impressively that his suggestions are generally put into effect simply because there is nobody of sufficient calibre to argue with him. Fortunately for the taxpayer most of Penney's hunches have proved to be winners. He combines the mathematical agility at figuring out possible methods of producing atomic explosions with a quite astonishing flair for designing the hardware which puts these ideas to practical test. It is a byword that Penney's weapons work with almost the exact performance he predicts. His virtuosity in these matters is so outstanding that an American State Department official has described his as "easily the best mind in the world on atomic and hydrogen bomb research".

Penney also has special aptitude for explaining the complicated workings of atomic weapons to the Staff Chiefs to whom he has to "sell" them, and this has been a most valuable attribute in getting the country atomically armed.

In addition he has some skill as a diplomat. He has made several trips to Washington for high-level talks on the interchange of atomic information and his ability has been one of Britain's best bargaining points.

In October 1951 Mr. Gordon Dean, then chairman of the U.S. Atomic Energy Commission, told the writer that he and his colleagues were satisfied that Britain had made important independent advances in the field of atomic weapons which might be of considerable advantage to the Americans. Yet in spite of enormous goodwill on the part of U.S. scientists, administrators and defence chiefs, politics prevented any interchange of weapons secrets.

When Penney visited Washington a few days later in an effort to secure the use of U.S. testing facilities at Eniwetok for the first British atom weapons test, he had no success. The U.S. law prohibited such an arrangement because it was argued that to discerning eyes the use of the testing equipment would necessarily reveal some features of the weapons for which the equipment had been designed.

Sir William has received several tentative approaches from U.S. organisations asking if he would be interested in a permanent post in America, but has persistently refused to leave Britain. So the Americans know that the only way they can get the benefit of his services is by coming into closer atomic partnership with Britain. (It is understandable why Penney should go down well with the Americans for Britain's leading armaments scientist is entirely disarming as a person. Like many Americans he is a slow, deliberate speaker, but he thinks fast and his mind works like a machete at cutting through details to get to essentials.)

Negotiations to restore the wartime partnerships have been long and arduous, but considerable progress has been made, as witnessed by the U.S. invitation to Penney and others to attend the first trial of an atomic anti-aircraft device in Nevada earlier this year. This was closely followed by the announcement of a new agreement which permits of wider interchange on methods of training troops in the use of nuclear weapons, on methods of defence against such weapons and on methods of finding out what foreign countries are doing in atomic weapons research.

Penney, who was born in Gibraltar and won his way to the university on scholarships, is essentially a theoretical physicist—a man who does most of his work with a slide-rule. He entered atomic research by a fluke of circumstance, his previous researches having been concerned with the structure of metals and crystals and general quantum physics. As assistant professor of mathematics at Imperial College, to which he was appointed when he was only twenty-seven, his name was on the National Register of scientists available for war work. Sir Geoffrey Taylor asked him to make a study of the blast effects of underwater explosions and this was his first introduction to weapons research. Working entirely with already published data, Penney soon developed a satisfactory mathematical theory of how blast travels and exerts its effects.

He was then put on to theoretical studies of the effects of waves on harbour structures for "Mulberry" —the transportable harbour to be erected off the Normandy coast. A few days before the Normandy landings in 1944 he joined the atomic project at the suggestion of the Americans and worked at the Los Alamos laboratory in New Mexico.

When Penney arrived at Los Alamos he found he was one of very few with practical experience of high explosives research and he was put on to studying the estimated blast effects of the weapon. He was able to assess the accuracy of his calculations when he helped to measure the force of the first atomic blast in the Alamogordo desert in July 1945.

Immediately after this he went to the Pacific island of Tinian as a member of the team responsible for assembling the atomic weapons for use against Japan.

It has never been officially stated that Penney was concerned in the design of the U.S. atomic weapons, but it is generally understood that he was involved in developing the extraordinary mechanism used for detonating fissile material.

The famous Smyth report about the U.S. atomic bomb project (*Atomic Energy for Military Purposes*) indicates that the first method considered for achieving an atomic explosion was the firing of one piece of fissile material at another so that the two together would exceed the critical size. The efficient use of fissile material depends on the bringing together of enough to form a more than critical amount within a fraction of a second. If the pieces are brought together relatively slowly a chain reaction begins prematurely and the explosion, though still large, may be only a "fizzle" compared with what should be achieved. A bomb working on this principle would be essentially a long steel gun-tube with a target of fissile material at one end and a bullet of fissile material at the other. A fuse would actuate the gun after the bomb was dropped so that the critical mass would be formed at the required height above ground. It is generally understood that the first weapon dropped over Hiroshima in August 1945 was a "gun-bomb" of this type.

Shortly after that mechanism had been devised, however, and long before it was used in action, scientists realised that there was another method of achieving the critical mass even more rapidly than was possible by the gun-tube device. This was the method which has come to be called "implosion". Its principle was revealed at the trial of David Greenglass, the U.S. soldier who worked at Los Alamos and was convicted of betraying atomic secrets to Soviet agents. In the implosion method a critical mass of fissile material is arranged in the shape of a hollow sphere, in which form it is safe. Surrounding the sphere and held at a certain distance from it are a number of high-explosive charges so shaped and arranged that when they explode the bulk of their blast is directed inwards towards the sphere. As all the charges are detonated simultaneously the blast exerts enormous pressure all round the sphere and therefore compresses it into a solid ball of extremely high density. In this form the fissile material becomes critical and the chain reaction takes place. The whole process is more rapid than the gun-tube method because detonation waves travel faster than any projectile. Furthermore the all-round pressure helps to hold the fissile material together after it has become gaseous and so allows a bigger build-up of atom-splitting neutrons. The first implosion bomb was dropped on Nagasaki and proved to be so effective that no more gun-bombs were made.

Penney was chosen to represent the British scientists as observer of the Nagasaki explosion and flew over the target with Group Captain G. L. Cheshire who represented the R.A.F.

In view of Penney's importance it is odd that the British Information Service statement on "Britain and the Atomic Bomb" released on August 12, 1945, mentioned him only once in a minor capacity. The American statement did not mention him at all.

Later Penney was a member of the British mission which examined the effects of the weapons in Hiroshima and Nagasaki and played a prominent part in estimating exactly where the bombs had exploded. While engaged on this work Penney noticed that empty petrol tins seemed to be a remarkably effective guide to the intensity of the blast. Empty tins scattered about the towns were deformed to an extent clearly related to their distance from the explosion. It was typical of the way in which Penney's mind works that he was able to put his observation to remarkable use at the later atomic tests at Bikini.

For the Bikini tests American scientists had devised some elaborate and highly sensitive instruments for recording the blast of the weapons. These instruments were trained on the point in the air at which the first bomb was expected to explode over the huge fleet of

discarded warships assembled in Bikini lagoon. Penney, who had been invited to serve as the co-ordinator of the study of blast effects in the tests as well as acting as chief British observer, decided to make use of petrol tins for recording the pressure at different points due to blast. He collected several hundred army tins, and fitted each of them with a cap made from a small square of metal and fixed to the tin with adhesive tape. These tins were then placed at various distances from the expected point of burst.

Unfortunately the crew of the high-flying bomber which dropped the weapon made an error, and the bomb fell wide of the target centre. The sensitive U.S. instruments therefore failed to record the blast properly, and it was only the results worked out by Penney from his tins which enabled the scientists to decide exactly where the bomb had burst. The U.S. scientists would have been able to work out the position of the explosion from photographs but this would have taken weeks whereas Penney was able to give them a rough position on the first day and an accurate one within a fortnight. He was also able to make a surprisingly accurate estimate of the power of the bomb.

After Bikini, Penney served for a time as scientific adviser to Sir Alexander Cadogan at the UNO discussions on the control of atomic weapons, and then returned to his former job at Imperial College and expected to continue his academic career. Several posts were open to him, and it is fairly certain that he would have obtained a chair at one of the senior universities. But because he was one of the few with a really good knowledge of explosives he was offered the post of Chief Superintendent of Armament Research in the Ministry of Supply and since he is the type who puts the needs of national defence before his personal ambitions he accepted it for a two-year period.

Most of his time was spent "running down" the wartime establishment to peacetime strength, but during this period the cold war developed and it became obvious to Penney that peace could not be assured until the weapons he had helped to devise were controlled by international authority. He believed that failing this it would be essential for Britain to develop atomic weapons if the nation was to remain a major power. So theoretical work on atomic weapons was stepped up, though it was not until 1948 that the Government provided the funds for work to begin in earnest after Penney had assured defence chiefs that his team could make a workable bomb without American "know-how".

During that time Penney had been based at Fort Halstead, an old defence point built against Napoleon's threatened invasion of England and used throughout the war as a secret armament research station. It was mainly here and at Woolwich Arsenal that Penney, with his small but able team, designed the atomic weapons which were eventually tested with conspicuous success in Australia at Monte Bello Islands and at Woomera.

For several years the Press was forbidden to mention Dr. Penney's name in connexion with atomic weapons research under a general defence notice.

It was realised from the first that Fort Halstead would be unsuitable for a full-scale atomic weapons establishment if only for space considerations. So a large airfield at Aldermaston, Berks, was chosen as the site for Britain's "Los Alamos". Penney quietly moved there at the end of 1952 but the news of his arrival quickly leaked out and the security authorities realised that the existence of the Aldermaston research station could no longer be kept secret.

The official announcement confirmed gossip which had been going the rounds of the village pubs in the Aldermaston area for a long time. The origin of these rumours is amusing and their ultimate confirmation ironic. At the end of the war Associated Electrical Industries decided to buy a large hall in Aldermaston for use as a central research station. They put Dr. Thomas Allibone in charge of it, and the fact that he had been given considerable publicity as a wartime atomic scientist convinced the Aldermaston residents that the station was for atom bomb work. A great deal of good "Public Relations" work by Dr. Allibone and his staff had almost convinced the villagers that their fears were unfounded when the Government decided to take over the nearby airfield for atomic bomb work!

Fortunately Penney's talents have not been wasted in administrative detail and he has managed to avoid serving on too many committees. Admiral Patrick Brooking was recalled from retirement to take over the bulk of the desk work, and when this grew more ponderous Mr. W. R. Cook was added to the Aldermaston team.

The success of the Monte Bello test came as the climax to years of work which justified the complete confidence which defence chiefs and Cabinet Ministers had placed in Penney from the first. It was typical of Penney's economical planning that it was no mere repetition of the first U.S. test to which it corresponded. At Penney's suggestion the weapon was exploded in the hold of a ship so that the test would also serve as the world's first trial of an atomic bomb as a sabotage weapon. The test was designed to assess what would happen if an atom bomb were smuggled into a British port aboard a small, inoffensive-looking ship. The 1450-ton frigate *Plym* carrying the bomb below deck was anchored close inshore in a Monte Bello Island lagoon, which had been chosen for this test because it resembled a typical British harbour in shape and size. Then the bomb was detonated by radio control from a ship many miles away—as it might be in a real sabotage attempt.

Penney had made detailed calculations of the expected effects of the explosion and in spite of the novel situation these proved to be astonishingly accurate. As Sir Winston Churchill said, "The weapon behaved exactly as expected and forecast in many precise details by Dr. W. G. Penney whose services were of the highest order."

The evidence of Senate hearings and probing committees in America shows that the British members of the bomb design team at Los Alamos knew all the facts about the weapons used against Japan, and it seems likely that the first British weapon tested at Monte Bello used the same principles, though no doubt with considerable refinement. It is generally believed, for

instance, that the all-up weight of the weapon (the Hiroshima bomb weighed about four and a half tons) was considerably reduced as a result of the researches of Penney and his team.

Penney himself gave the first detailed news of the Monte Bello explosion in a B.B.C. talk. No assessment of its power was given but two of the facts suggest that the weapon was considerably more powerful than the U.S. bomb exploded at Bikini. Firstly, the scientists had to go more than twelve miles away from the bomb to be sure of being safe from flashburn and "fall-out". Secondly, the cloud, although weighted with thousands of tons of mud and debris from the sea-bed, went twice as high as the Bikini cloud.

Later an excellent documentary film of the test, which was called *Operation Hurricane,* was shown to the public. In one shot the observant could see Penney helping to manhandle stores from a boat. (Penney's personality has been unaffected by his rapid rise to international fame. He remains unconventional, and his aides say that he is often found studying papers sitting on the floor propped against the radiator.)

Until just before the Monte Bello test Penney's telephone number was in the London phone book. It was changed and made ex-directory for security reasons. Indeed it became so difficult to contact Penney by telephone that even Sir Winston Churchill had difficulty when he wished to tell him that he was to be knighted. The telephone operator at first refused to give the number to the Prime Minister's secretary!

The security arrangements covering Penney's flight to Australia had an amusing sequel. The security men decided on a plan to fool foreign agents into believing that the Monte Bello atom test would be in November instead of early in October. They called it Operation Spoofer. Seats on separate B.O.A.C. planes were booked in the names of Dr. Penney and other atomic chiefs. The security men were confident that the bookings would leak out through the Press and mislead foreign agents. The plan misfired because nobody heard of the bookings and Operation Spoofer was abandoned. Nobody remembered to cancel the seat bookings, however, so *after* the bomb had gone off news of the bookings leaked out. It seemed that the atom men were returning to Australia for a second test—until one of the security men finally cancelled the bookings.

The weight of fissile material in the early weapons—the so-called critical mass—can be calculated as being of the order of twenty-two pounds. Originally it was thought that no reduction of this mass was possible but progressive improvements of the implosion principle have changed this position. Because of the pressures developed during implosion, greatly increased densities of fissile material at the moment of the chain reaction are now possible. Under these conditions the critical mass for an explosion is considerably reduced and a series of so-called "sub-critical bombs" has been developed. Because of other refinements in bomb design some of these give an explosion as great or even greater than those achieved over Japan with considerable saving in fissile material. Others are deliberately designed to give smaller explosions so that the weapons can be used for localised tactical purposes against troops on the battlefield.

There can be little doubt that as a result of further work by Penney and his team such "sub-critical" weapons are in the British stockpile. These, the writer understands, include warheads for guided missiles.

Work along such lines proceeded steadily after Monte Bello and by October 1953 Sir William and his team were ready to test another weapon on a new test site built in the South Australian desert several hundred miles west of Woomera. The writer had the privilege of watching this test, which was code-named *Operation Totem.* The weapon was never officially referred to as a bomb and it is believed that it was a "sub-critical" weapon which could be used either as a tactical bomb or as a warhead for guided missiles.

Sir William provided some briefing notes on the night before the test and his description of what the explosion would be like was uncannily accurate. Thus he forecast a double bang on the basis of prevailing weather conditions, and a double bang it proved to be.

The Press was not allowed to see the second explosion which the writer understands to have been a test of a novel device with far-reaching consequences. It is believed that this test had some direct bearing on thermonuclear devices and it is on the basis of its success that the Government has been able to announce its capacity to make thermonuclear weapons. These weapons, which are still to be tested, are being developed from scratch without benefit of American help or know-how. There are reasons for believing that the Penney team has devised weapons which will be cheaper to produce than their U.S. counterparts.

At the time of writing no British thermonuclear weapon has been tested and it is unlikely that any will be ready for test for quite a long time. Since the disastrous effects of the radioactive "fall-out" from the U.S. thermonuclear explosions at Bikini there is the additional difficulty of finding a site for the H-bomb test and it seems that some island site probably in the Pacific will have to be acquired. Such a test will certainly have to be carried out before stockpiling begins. The scientists could be satisfied that they had produced a workable weapon but they would never be able to "sell" it to the Services before it had exploded satisfactorily.

Penney is not worried by moral qualms about making the H-bomb because he believes that it is the best existing safeguard of peace. He thinks that the certainty of mutual destruction will probably outlaw large-scale war though he dryly comments that there are always madmen around.

Shortly after the Woomera test it was decided that Sir William should become a director of the proposed Atomic Energy Authority which was to be set up to take the atomic project out of the hands of the Civil Service and he is now one of the most highly paid scientists in Britain. There had been a certain amount of departmental manœuvring with a view to keeping the Aldermaston establishment within the Supply Ministry, but eventually it was decided that Penney and

his team should become part of the new Authority.

Penney still itches to get back to academic work and has vague regrets at giving up university life but he realises that if he gave up his job there might be difficulty finding anyone of standing willing to replace him. The fact that he is well into the forties increases the likelihood that he will stay in atom work, for Penney is a firm believer that scientists do their best work before they are forty and find it hard to switch to new problems after that time.

He still manages to do a little academic research—mainly on the subject of explosives and fortunately is not worried by the fact that he cannot publish it, as many scientists are. Indeed he finds security bans are often useful since they save him from the chore of writing up his studies for publication.

Profiles of Penney list him as a golfer with a handicap of eight and an expert at the "explosion shot". He still plays but only about three times a year, so—to use his own words—his handicap is "hardly realistic".

Penney never attempts to correct such errors about himself in Press reports. He says he does not mind what inaccurate things are said about him. He only gets worried when they are right!

A PIONEER OF REFRIGERATION

W. R. BETT, M.R.C.S., L.R.C.P.

On July 14, 1850—Bastille Day—Monsieur Rosan, cotton buyer and French consul in the busy seaport of Apalachicola, Florida, was giving a dinner at the old Mansion House. Considerable anxiety assailed the minds of his distinguished guests from West Florida and South Georgia, for it had been a oppressively warm day, the boat from Portland, bringing the promised ice—an expensive luxury in those days—had not yet arrived, and the supply of stored ice was exhausted. A stockily built man of medium height with a large head, dark hair, keen black eyes, and sallow, rather sad complexion suggesting Spanish ancestry, rose to offer the first toast: "To our sister republic, France, we drink in warm red wine." Dr. John Gorrie, physician and one-time postmaster and mayor of the city, was followed by another physician—the celebrated botanist A. W. Chapman: "Our own country we toast in sparkling cold champagne, chilled by the genius of an American." The smile of utter incredulity on the lips of the diners quickly faded when four waiters entered carrying ice cubes on silver trays.

How came it about that a busy medical practitioner, who had had no training in physics or in engineering, found time to invent a process for making artificial ice?

Gorrie's essentially tragic story may briefly be told. According to the *Dictionary of American Biography* he was born on October 3, 1803, at Charleston in South Carolina. John studied medicine (probably as a postgraduate student) at the College of Physicians and Surgeons in New York, where he graduated M.D. in 1833, and spent the remainder of his short life at Apalachicola.

During the summer months subtropical fevers were a menace to the health of the inhabitants and a threat to commerce and to successful colonisation, and Gorrie, though ignorant of the mosquito's role in their transmission, advocated measures which were fundamentally sound: by draining out and filling up the low swampy places he prevented stagnation of water and decreased moisture. Interested in the control of temperature both in the prevention of malaria and in the treatment of its victims, he ingeniously designed a room without windows or doors, but with an opening in one wall at floor-level. A block of ice was suspended in a bowl surmounted by a cone-shaped hood with a vent pipe leading through the ceiling into the chimney. The air drawn by suction through the vent over the melting ice was partially purified by being filtered through the soot carbon in the chimney and, being cooled, descended to the floor and out through the opening. A room thus cooled, thought Gorrie, should be safe from malaria.

Though this scheme proved irrelevant to the solution of the malaria problem it did open up ideas on air-conditioning.

From air-conditioning Gorrie went on to refrigeration projects, and on May 6, 1851, he was granted a patent for his machine for making artificial ice, on which he had been working secretly for ten years and which was constructed on the principle that gases which are permitted to expand rapidly absorb heat from substances about them. It consisted of a double-action or compressor pump which increased the pressure of air in a chamber, a container within the chamber holding water which froze when the gas was allowed to expand. His greatest difficulty is said to have arisen in getting the ice out of the container. He tried various methods such as greasing the container, but never thought of the simple expedient of immersion in warm water.

Gorrie's machine was probably the first constructed on the cold-air principle. Artificial cooling by liquefaction was employed in ancient times, and the melting of saltpetre to reduce the temperature of liquids was familiar to the Romans. The first machine for producing artificial ice on the vacuum principle was designed in 1755 by the Scottish physician William Cullen, while an American, Jacob Perkins, is generally regarded as the pioneer of the compression process in 1834.

When Gorrie tried to develop his apparatus commercially, he met with scepticism and ridicule, until a Boston financier agreed to put up the money in return for a half interest in the project, but he died before the negotiations were completed. Bitterly disappointed, the inventor fell a prey to melancholy, suffered a nervous breakdown, and died at Apalachicola a century ago on June 16, 1855, at the early age of fifty-two.

THE PHYSICS OF RAIN-MAKING

B. J. MASON, M.Sc.

The joint rain-making experiments of the Meteorological Office and the Ministry of Supply have begun, with a test carried out on Salisbury Plain on October 5, using silver iodide to induce precipitation. This article by B. J. Mason of the Dept. of Meteorology of the Imperial College of Science and Technology, explains the fundamental processes involved in rain formation and the way in which substances such as silver iodide produce their effect.

The demonstration in recent years that suitable clouds may be made to rain by seeding them with dry ice, silver iodide, water droplets, salt particles, etc., has created the greatest interest and controversy. To what extent future development of these techniques may allow man to exert some control on the weather is difficult to foresee, but one thing is certain: the first experiments have given a tremendous impetus to research in the fundamental physics of clouds and precipitation.

To appreciate how crystals like silver iodide can trigger off the rain-forming processes, one needs to understand how an individual raindrop comes into existence. Much of this article will therefore be concerned with the basic physical processes responsible for the natural release of precipitation (snow, rain, hail). The factors of prime importance are the motion of the air, its water-vapour content, and the numbers and properties of those particles which it contains and which act as centres of condensation and freezing. Because of the great complexity of atmospheric motions and the enormous variability in the vapour and the particle content of the air, it is not possible to construct a detailed, general theory of the manner in which cloud and precipitation will develop. However, considerable progress has been made in recent years with calculations, based on simple models of the air motion, of the growth of individual cloud particles, and these give a reasonable explanation of the formation of precipitation in different kinds of clouds. Let us consider some of the important results which have emerged from these studies.

MECHANISMS OF PRECIPITATION RELEASE

Today a great deal is known about cloud formation. We know that that clouds are formed by the lifting of damp air which cools by expansion under continuously falling pressure. The relative humidity increases until the air approaches saturation, when condensation occurs on some of the wide variety of aerosol particles which are present in average concentrations of a few hundred per cubic centimetre. A proportion of these are hygroscopic and promote condensation at relative humidities below 100%, but for continued condensation leading to cloud-droplet formation the air must be slightly supersaturated. An important source of efficient condensation nuclei is the finely divided salt resulting from sea spray over the oceans, but it now appears that particles produced by man-made fires and by natural combustion (such as forest fires) may also make a major contribution. Condensation on to nuclei continues as rapidly as the water vapour is made available by cooling of the air and gives rise to droplets of order 1/100 millimetre in diameter. These droplets, present in concentrations of a few hundreds per cubic centimetre, constitute a non-precipitating water cloud. Now we shall see how the transformation into a rain-bearing cloud takes place.

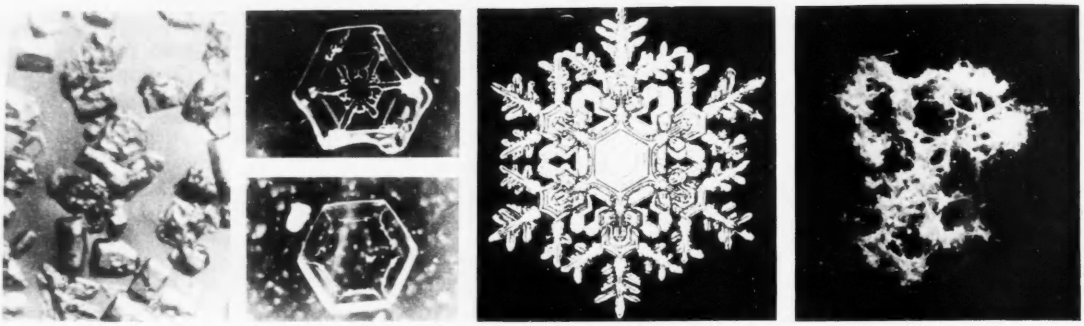
Growing clouds are sustained by vertical air currents which may vary in strength from several centimetres/sec. to several metres/sec. Considerable growth of the cloud droplets which have falling-speeds of only 1 centimetre/sec. is necessary if they are to fall through the cloud, survive evaporation in the unsaturated air beneath and reach the ground as drizzle or rain. Drizzle drops have radii exceeding a tenth of a millimetre, while the largest raindrops are 5 millimetres across and fall faster than 8 metres/sec. The production of a relatively few large drops from a large population of much smaller ones may be achieved in one of two ways.

The coalescence process. Cloud droplets are not, in general, of uniform size because they arise on nuclei of various sizes, grow under slightly different conditions of temperature and supersaturation in different parts of the cloud and some may remain inside the cloud for longer than others before being carried to the drier air outside.

A droplet which is larger than average will fall faster than the smaller ones and so will collide and coalesce with some of those lying in its fall path. Once a drop starts to grow by this process, it will continue at an ever-increasing rate, because after each collision it becomes bigger, falls faster and so sweeps out a larger volume of cloud more quickly. If its journey in the cloud is sufficiently long and if the population of smaller droplets is sufficiently dense, it may eventually grow large enough to fall through the cloud base as a raindrop.

The ice-crystal process. One of the fundamental features of natural water clouds is their frequent occurrence in the super-cooled state, i.e. the water droplets exist at temperatures below 0°C—sometimes down to −40°C. At temperatures above −40°C water droplets can freeze only if infected with small solid motes possessing certain favourable properties; these freezing agents are called ice-forming nuclei. At temperatures just below 0°C the probability of a cloud droplet containing a suitable nucleus is very small, but at lower temperatures this probability increases as more and more airborne particles become capable of initiating crystallisation of the supercooled water.

In general, then, that part of the cloud which lies between the 0°C and −20°C levels consists of supercooled droplets co-existing with a much smaller number of ice crystals. Since the equilibrium vapour pressure over water is greater than that over ice at temperatures below 0°C, air saturated with respect to water will be appreciably supersaturated relative to ice, so that the ice crystals will grow much more rapidly than the water droplets.



(a) (b) (c) (d)

FIG. 1. (a) Ice crystals in the form of hexagonal prismatic columns.
(b) Thin, hexagonal plate-like crystals (which are about 800 μ across).
(c) A hexagonal plate showing branching at the corners to form a delicate star-shaped structure.
(d) A snowflake consisting of an agglomerate of star-shaped crystals.

The ice crystals grow in either of two main forms depending on the temperature—as hexagonal prismatic columns or as thin hexagonal plates. In their later stages of growth, the latter may sprout at the corners to form richly branched star-shaped crystals, several of which may aggregate to form a snowflake. These features are shown in Fig. 1. On falling through the level at which the temperature becomes 0°C the snowflake will melt to form one or more raindrops.

Ten years ago, most meteorologists were firmly of the opinion that only this second mechanism was of importance and that all rain was produced by the melting of snowflakes. However, recent observations show beyond all doubt that heavy rains often fall in tropical and subtropical regions from clouds which are entirely beneath the 0°C level and cannot therefore contain ice crystals. And, even in temperate regions, during warm weather, there is evidence that showers are sometimes produced by the coalescence process.

It is worth considering, in a little more detail, the roles played by the coalescence and ice-crystal mechanisms in natural clouds, and it is convenient to distinguish between layer (stratiform) clouds and shower (cumulus) clouds.

PRECIPITATION RELEASE FROM LAYER CLOUDS

The extensive sheets of stratiform cloud, from which falls precipitation of a steady, persistent character, are generally formed in cyclonic depressions and near fronts and are associated with feeble up-currents of only a few centimetres/sec. which are maintained for at least several hours. The structure of these great rain-cloud systems can be examined satisfactorily only by observers using aircraft and by radar, and their systematic exploration has hardly begun. But analysis of the available aircraft data shows that while drizzle often falls from non-freezing stratiform clouds in which the drops must be growing by coalescence, the majority of these clouds produce rain when their tops are colder than −12°C, which suggests that ice crystals may be responsible. This view is supported by the radar evidence; the variation of the strength of the radar signal with height indicates that ice crystals grow in the cold upper regions of the cloud, then they coalesce to form snowflakes as they approach the 0°C level, and finally the snowflakes melt to form raindrops. Because the melting snowflakes produce a very characteristic radar signal, the appearance of the latter shows that the rain is being released by the ice-crystal mechanism, which is responsible for most of the rainfall in temperate latitudes.

THE PRODUCTION OF SHOWERS

Precipitation from shower clouds (which may reach the ground in the form of raindrops, pellets of soft hail or as larger hard hail-stones) is generally of greater intensity and shorter duration than that from layer clouds, and is composed of larger particles. The clouds themselves are characterised by their great vertical depth, and the strong vertical air currents and high concentrations of liquid water in them; all these factors ensuring the rapid growth of the precipitation particles by coalescence.

In a cloud composed wholly of water, raindrops must grow by coalescence with smaller droplets, and for this process to start some droplets must be larger than average. In layer clouds which may persist for days, these larger droplets may be developed *in situ:* in shower clouds, whose active life may be restricted to only a few minutes, this appears impossible, and the larger droplets have to be introduced ready-made from an external source. Now over the oceans, droplets of sea water formed as spray and having diameter of about a twentieth of a millimetre may be carried up by convection currents to the cloud base without appreciable evaporation, and may thereafter be capable of initiating a shower. While being carried up through the cloud, such a droplet will grow by sweeping up smaller cloud droplets until it is too heavy to be supported by the vertical air currents; it will then fall, continuing to grow by the same process on its downward journey, and if the cloud is sufficiently deep it may emerge from the base as a raindrop.

In a dense, vigorous cloud of considerable depth, the

FIG. 2. Stratified hailstones which fell in Richmond, Yorks, on July 8, 1893. The largest stones are 2 inches in diameter.

drop may attain its limiting stable diameter (about 5 millimetres) before reaching the cloud base; it will then break up into several large fragments, each of which may continue to grow and itself attain break-up size.

The number of raindrops may increase so rapidly in this manner, that, after a few minutes, the accumulated mass of water can no longer be supported by the up-currents, and so a heavy shower is released. The conditions which favour this rapid multiplication of water drops occur more readily in tropical regions.

In temperate regions, where the 0°C level is so much lower, conditions are relatively more favourable for the ice-crystal mechanism, although many showers may be released by the coalescence of water drops.

The ice crystals will grow initially by sublimation of water vapour in much the same way as in layer clouds, but when their diameters exceed about a tenth of a millimetre, growth by collision with supercooled water droplets will predominate. The droplets freeze on impact to form pellets of soft hail. Because air spaces are formed between the frozen droplets, the average density of the particle may be as low at 0·3 or even 0·1, so that in a dense cloud it would increase very rapidly in size. However, the growth of the particle is restricted by the fact that it may collect supercooled water at a rate faster than it can be frozen and so acquire a liquid coat which, on subsequent freezing, produces a layer of clear ice. Alternate layers of opaque and clear ice are characteristic of large hailstones (see Fig. 2). Their formation may be interpreted in terms of alternate periods of wet and dry growth associated, perhaps, with the passage of the hailstones through regions of high and low liquid-water content and of strong and weaker up-draughts in the cloud.

In a warm, dense vigorous cloud the wet hailstones may accumulate excess water at such a rate that large drops may be flung off and continue to grow by coalescence to disruption size. Thus the water-drop "chain reaction" may be initiated by the shedding of water from a very small population of wet hailstones. The alternative mechanisms for releasing precipitation from both shower and layer clouds are summarised in the diagram.

THE ARTIFICIAL STIMULATION OF PRECIPITATION

We have seen that the presence of either ice crystals or comparatively large water droplets (to initiate the coalescence process) appears essential to the natural release of precipitation. Rain-making experiments are conducted on the assumption that some clouds precipitate inefficiently, or not at all, because these natural nuclei are deficient; and that this deficiency can be remedied by "seeding" the clouds artificially with "dry ice" or silver iodide (to produce ice crystals) or by introducing water droplets or large hygroscopic nuclei.

Three different methods have been tested in rain-making experiments. In the first method pellets of dry ice (solid carbon dioxide), about a centimetre in diameter, are dropped from an aircraft into the top of a supercooled cloud. Each pellet cools a thin sheath of air near its surface to well below −40°C and produces perhaps 10,000 billion minute ice crystals, which subsequently grow and coalesce to form snowflakes. Thus only a few pounds of dry ice are required to seed a large cumulus cloud. More than two hundred experiments, carried out in Australia, Canada and South Africa, have shown beyond all reasonable doubt that

FIG. 3. A V-shaped pattern of ice crystals produced in a thin, supercooled layer cloud by seeding with dry ice. Dry ice was dropped from an aircraft at the rate of 1 lb. for every mile flown, and the photograph was taken 36 minutes after the loop in the upper part of the picture had been seeded. The ice crystals transported to the edges of the seeded lane grew large enough to fall out of the cloud, leaving a long rectangular hole. (*Courtesy, General Electric Company, Schenectady, U.S.A.*)

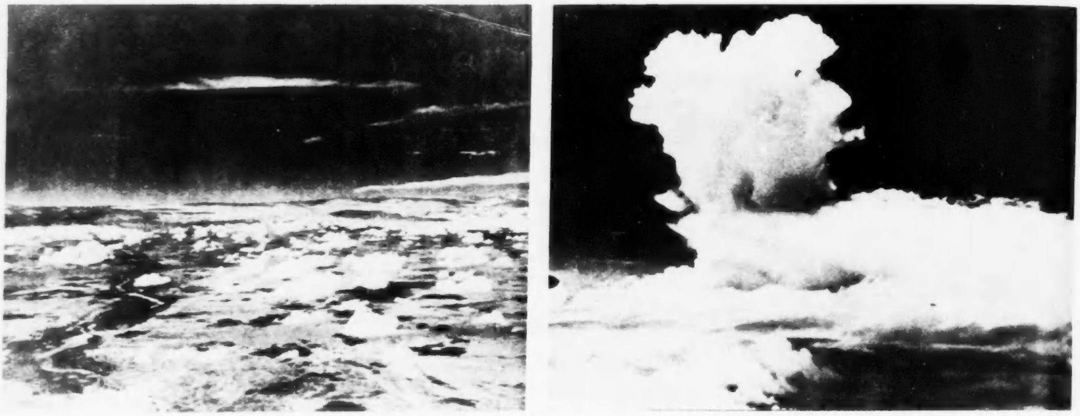


FIG. 4. (*a*) Area of New Mexico before cloud-seeding operation. The cumulus clouds are small with bases at about 15,000 feet; their tops are supercooled. (*b*) One of these clouds towering upwards 20 minutes after seeding. (*Project Cirrus, U.S. Signal Corps Engineering Laboratory.*)

cumulus clouds in a suitable state of development can be induced to rain by seeding them with dry ice whereas neighbouring clouds which are unseeded do not precipitate. (See Figs. 3–4.)

However, for large-scale trials designed to modify the rainfall from widespread cloud systems extending over thousands of square miles it is uneconomic to use aircraft. This consideration led to the development of the second technique; silver iodide is released from the ground in the form of a smoke, and air currents carry it up into the supercooled regions of the cloud. Silver iodide was chosen because of the similarity of its crystal structure to that of ice; but an adequate explanation for its particular efficiency as an ice-forming nucleus awaits further research. It produces ice crystals in relatively small numbers at $-5°C$, and becomes fully effective at about $-15°C$, when one gram of iodide can be vaporised to produce some 1000 billion nuclei. Of course, with this method, one has no control over the subsequent transport of the smoke. We are unable to make a reliable estimate of the concentration of nuclei reaching cloud level, nor do we know for how long silver iodide retains its ice-nucleating ability in the specified atmospheric conditions. It is these unknown factors which, together with the impossibility of estimating accurately what would have been the natural rainfall in the absence of seeding activities, makes the design and evaluation of a large-scale operation so difficult. In the data so far published, one can find no convincing evidence that large increases in rainfall can be produced consistently over large areas.

Attempts to stimulate the coalescence process in shower clouds are a more recent development. Aircraft equipped with water tanks and spraying devices have been used to introduce droplets of mean diameter about a twentieth of a millimetre into the bases of growing clouds, thus providing the larger droplets necessary to start the coalescence process. The results of the first Australian experiments were encouraging; ten out of eleven experiments produced rain, and in four cases (where the cloud depth exceeded 5000 feet) the rain was heavy. Some success was achieved in some very recent tests with tropical cumulus clouds in the Caribbean. But in view of what has been said about the probable role of water droplets formed on large salt particles, and the fact that about four ounces of salt may be used instead of one gallon of water, it appears more economical to disperse salt crystals of about a hundredth of a millimetre in diameter instead of water droplets; the salt crystals being strongly hygroscopic would grow to droplets of the requisite size while being carried up through the bottom half-kilometre of the cloud. A few "salting" experiments involving aircraft were made in this country in 1952; further trials have been made in East Africa with balloon-borne bombs containing gunpowder mixed with finely ground salt, and in Pakistan where the dry climate has made it possible to disperse salt-dust from the ground. The results of these tests are encouraging, and suggest that this may prove an efficient method of releasing showers from warm cumulus clouds.

These experiments are most exciting and offer not a little hope of further development. Although, unfortunately, the significance of the first preliminary results were often greatly exaggerated, most responsible meteorologists would agree that they suggest possibilities which should not be ignored. Their investigation will, however, call for a considerable scientific effort. The time is rapidly approaching when thorough, carefully planned and systematic investigations of the possibilities of weather modification, will have to be carried out over an extended period. In the meantime, much has to be done to consolidate and extend our knowledge of cloud behaviour and the natural mechanisms of precipitation. Let us hope that the problems will be tackled with the imagination and enthusiasm that they deserve.

READING LIST

Mason, B. J., "Design and Evaluation of Large-Scale Rain-making Experiments", *Nature*, 1955, vol. 175, p. 448.

For a more detailed and technical discussion of cloud physics, see "The Microphysics of Clouds", by B. J. Mason and F. H. Ludlam, *Progress Reports in Physics* (Physical Society, vol. 14, 1951).

PROGRESS IN ELECTRONICS

The wonder of television is already lost to the millions who see and hear in their own homes events which may be occurring hundreds of miles away. It is already an accepted part of our lives, to be judged and debated not on its technical qualities, but on its value as an entertainment and its influence on our culture.

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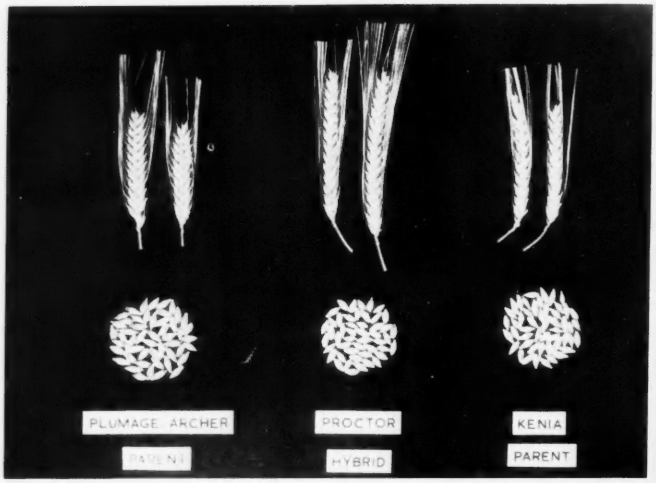


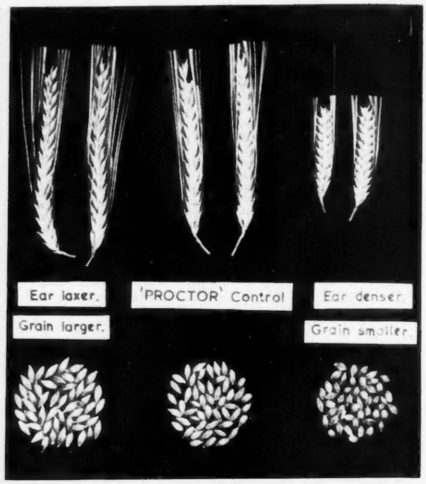
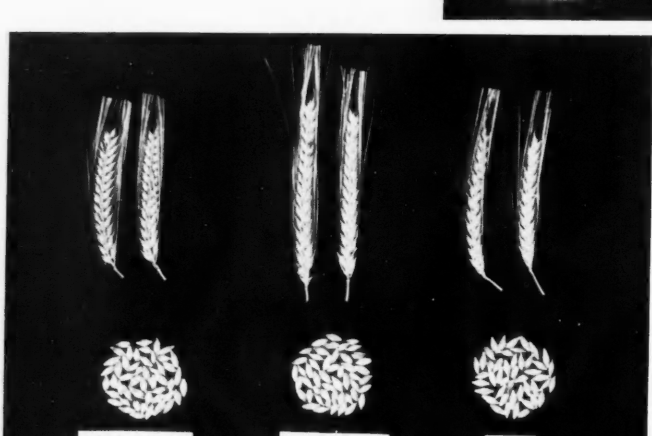


FIG. 1 (*top left*). The parentage of Proctor, an improved hybrid variety of barley released for cultivation in 1952, and now probably the most widely grown variety in England.

FIG. 2 (*top right*). Artificially induced mutations in barley resulting from irradiation of grain. The lax ear mutation was produced after exposure to x-rays at a dosage of 10,000 roentgen units. The small denser ear type resulted from exposure for 30 minutes to neutron irradiation.



FIGS. 3–4 (*above and left*). Two new hybrids, Provost and Maythorpe, were released for cultivation in 1954 and were grown by farmers on a limited scale this year.

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THE IMPROVEMENT OF BARLEY

AN ACHIEVEMENT IN PLANT BREEDING

G. D. H. BELL, Ph.D.

The improvement of agricultural crops by plant breeding involves a wide range of scientific and agricultural considerations, which actually determine the methods and the objectives of any breeding programme. Agriculture is a highly diversified and technical industry which is becoming increasingly dependent on scientific research for the maintenance and improvement of its efficiency, and the continued exploitation of its potentialities. It is usually the case that the problems posed to the plant-breeder for solution by improving the varieties available to the grower are concerned with production, handling, marketing, processing or consumption. This situation is complicated from the breeders' point of view, because in addition to involving biological considerations, and the appreciation of the wider aspects of husbandry and farm management, there is commonly the problem of trying to reconcile the requirements of the producer and the consumer.

The position can be resolved and expressed simply, however, by associating the breeding objective with the characters of the plant that need attention to bring about the necessary improvement. Is it disease-resistance, earliness, winter hardiness, strength of straw, the chemical composition of the grain, or more generally all the characters that determine yield? This identification of a breeding objective with a biological concept is important because it determines the feasibility of a programme of research in crop improvement. It usually means that every aspect of the biology of the crop—its reproduction, genetics, cytology, physiology, pathology and ecology in particular—must be understood, because it is on this knowledge that the biological possibilities of improvement depend and the techniques of breeding are based.

And so the breeder is ultimately thrown back on exploiting genetic variation either by searching among naturally occurring forms, or by creating new sources of variability through hybridisation, artificial mutations, or artificial polyploids (multiple chromosome forms). Hybridisation, followed by selection among the offspring, is the most common method of breeding among such crops as the cereals grown in this country, and it is the method that has proved the most successful. It does involve, however, protracted selection over several generations, and usually the selection is concerned with more than one complex inherited character not showing simple modes of inheritance. Complex genetic behaviour is, therefore, the common experience with plant-breeding material, and carefully controlled methods of selection and of assay have to be used. Indeed, the techniques of the statistician, the chemist, the physiologist, the mycologist and the entomologist may all be employed, while genetic analysis and synthesis are basic to the study of the behaviour of the hybrid populations involved.

THE AGRICULTURAL AND SCIENTIFIC BACKGROUND

Barley is one of the three important cereals of this country, occupying some 2 million acres and having a farm gate value of something like £65 million. The economy of the crop depends, of course, on its utilisation, and the most important outlets are for feeding, malting and distilling. As nearly half the crop may be used for livestock feed and a third for malting, these two methods of consumption virtually determine the growers' requirements regarding the kinds of varieties, as well as largely controlling the cash value of the crop. In both cases, however, yield per acre is the vital consideration, but in the case of barley grown for the maltster the *quality* of the grain is of the utmost significance: the maltster will only purchase grain of suitable quality, and the price he pays for it depends on its quality.

Although yield and quality are inherited varietal characters, both are strongly affected by growing conditions, and the best barley-growing areas are characteristically localised. In Britain 80–90% of the crop is grown within the boundaries of England, and five eastern counties contribute 50–60% of this acreage. This is primarily because barley grows to the best advantage in the low rainfall areas, and is eminently suited to the lighter and more alkaline soils which are characteristic of these eastern parts of England. The bulk of the crop is spring-sown, and being a relatively quick-growing plant, barley suits the farming systems in these primarily arable areas where most growers concentrate on the malting market.

The grower requires certain major characteristics in the varieties he grows, and these are decided primarily by climate, soil and consumer demands. Recent changes in husbandry practice have, however, underlined the importance of certain features that a variety must have if it is to become popular. Thus the more intensive use of fertilisers, coupled with the phenomenal development of mechanisation with the rapid spread of the combine harvester, has served to emphasise the importance attached to high yield, strong and short straw, and earliness of ripening. These are now the main agricultural considerations in barley breeding, but such characters need to be superimposed on good malting characters of the grain if a new variety is to have any great success. But it is most desirable also to maintain a high standard of resistance to the fungal diseases Loose Smut and Mildew, while in certain areas there is a demand for a variety possessing winter hardiness in addition to the above attributes.

Barley has been subjected to intensive study from all the more important aspects of its cultivation, improvement and commercial utilisation for over fifty years, and an extensive literature exists on barley as a plant, a

crop, and an end-product that has direct utilisation for feed and for processing in the malting, brewing and distilling industries. Cultivated barleys exist in a wide range of botanical forms and types which have world-wide distribution, and the botanical relationships, growing condition requirements and suitability for particular purposes of these forms and types are now well understood. Genetic investigations, accompanied by chromosome studies, have led to the accumulation of a considerable amount of knowledge on the inheritance of plant characters, some of which are extremely important to the plant breeder. A great deal is now known about the physiology of the barley plant, and this has helped considerably in the understanding of field behaviour, yield potentialities and grain quality. Commercial interests have concentrated much attention on the chemistry, biochemistry and biology of the malting and brewing processes, and every effort has been made to correlate the results of these diverse researches to give a sound basis for breeding better barley varieties.

The knowledge and experience gained with barley have made quite clear the general framework within which the technical problems of breeding can operate, and the crop has proved itself very amenable to improvement. This is partly due to the considerable range of genetic variation available for breeding purposes, and the position has been exploited with success by breeders in this and other countries who have concentrated on carefully devised hybridisation programmes for the detailed synthesis of improved varieties. The success of the breeding, however, is largely the result of the comprehensive researches on barley genetics, physiology and grain chemistry. Although it is probably true to say, however, that the physiology of barley is better understood than the genetics of complex economic characteristics, nevertheless genetic analysis in barley has made considerable progress in presenting a working scheme for the breeder. Apart from establishing modes of inheritance of characters, it has been possible to recognise genetic linkage groups and to map chromosomes. Ultimate knowledge on the precise mode of inheritance of all characters is, of course, not essential for crop improvement, although a sound basis of genetic knowledge is necessary if breeding methods are to be reasonably exact. But it is the pure and applied physiological research that the barley breeder recognises as being of equal value and promise in determining the future possibilities for improvement involving the most important economic and agricultural characters.

BREEDING NEW BARLEYS

Most of the malting barley grown in this country is spring-sown and, as has been indicated above, is of a restricted botanical type although several named agricultural varieties are concerned with the total production. It should be realised, of course, that before the more modern era of barley breeding with which we are primarily concerned, a great deal had been done to try and improve the crop. For many hundreds of years the varieties grown were genetic mixtures and were grown locally under such names as "Old Wiltshire" and "Long-Eared Nottingham", but most of these varieties showed distinct characteristics and had been subjected to some form of selection based largely on the local requirements.

Historically the story is interesting, and significant scientifically, in showing the limitations of one breeding technique with the subsequent development of others offering wider scope and greater potentialities. Selection within populations offers opportunities for improvement only in so far as there is adequate genetic variability available and provided also the selection methods are effective in isolating the desired type. Some of the earlier improvements in barley of which there are authentic records were the result of deliberate, but chance, selections. The development of the variety Chevalier in 1824, for example, involved an interesting stage in the selection stage of barley varieties, as also did Goldthorpe in 1889, but these two varieties marked the end of an epoch where improvements were more or less haphazard, although in both cases the new variety was the result of selecting a single outstanding plant; that is, a "single plant selection" in breeding terminology.

Although both Chevalier and Goldthorpe barleys had considerable success, the former indeed occupying most of the barley acreage in this country at the beginning of this century, it soon became clear that rectifying the weaknesses of these barleys, or making any worth-while improvements, was not likely to be accomplished by the old haphazard methods. It was for this reason that the first properly conducted investigations were started. These involved controlled selection based on single plants and their offspring, with field tests to compare these selections with the older varieties in cultivation. These experiments demonstrated clearly that selected forms of the old Archer barleys were superior in yield, strength of straw and cash value to Chevalier, Goldthorpe and Standwell varieties, there being a superiority in yield of 8% compared with Goldthorpe and 20% compared with Standwell. Further systematic selection of Archer barley resulted in improvements in grain quality and uniformity, and set the seal on the value of this method of breeding which is based on selection of individual or single plants with the subsequent methodical testing of their progenies.

It was soon realised, however, that single plant selection in these varieties was not likely to achieve anything further in the way of worth-while improvement, and breeders consequently turned to hybridisation. Two hybrids, named Spratt-Archer and Plumage-Archer respectively, were produced in the first two decades of this century. They are among the most spectacular achievements in the breeding of any crop, and undoubtedly revolutionised barley growing in this country. The first Plumage-Archer strain was marketed in this country in 1914; Spratt-Archer did not appear in England until 1920. Spratt-Archer showed a 10% improvement in yield over Archer, and the grain was of better quality. Plumage-Archer has had great success because of its improved field characters like Spratt-Archer, and also because of its capacity to produce grain of outstanding quality. Over a period of many years, starting in 1925, national trials demonstrated the

TABLE I

INCREASE IN BARLEY YIELDS IN ENGLAND AND WALES

1920–9	15·6 cwt. per acre
1930–9	16·2 cwt. per acre
1940–9	17·8 cwt. per acre
1950	19·0 cwt. per acre
1951	20·2 cwt. per acre
1952	19·9 cwt. per acre
1953	22·6 cwt. per acre
1954	21·4 cwt. per acre

TABLE III

THE INCREASED YIELD OF PROCTOR

The results are based on National Institute of Agricultural Botany Trials at eighteen different centres; the yield figures shown are percentages of the yield for Kenia.

	1949	1950	1951	1952
Cambridge	104	**116**	**113**	—
Askham Bryan	**121**	**132**	—	—
Cannington	—	**117**	96	**112**
Cockle Park	—	—	110	—
Edinburgh	—	—	F*	—
Newport	**114**	**110**	**109**	—
Seale-Hayne	—	—	94	100
Sparsholt	**129**	**135**	F*	—
Sprowston	—	**112**	106	—
Sutton Bonington	**114**	**119**	**121**	—
Wye	**116**	**135**	—	—
East Yorks. (I)	**108**	101	**115**	—
East Yorks. (II)	**111**	**120**	102	**110**
Devon	—	**111**	**112**	109
Gloucester	—	**130**	—	**119**
Hereford	—	101	—	105
Notts.	—	**112**	**113**	98
Trawscoed	—	—	—	**120**

*F = trial failure.

All figures in **bold type** represent a yield significantly different from the control barley yield

superiority of these two varieties over all others tested, and consequently they were the most remunerative for farmers to grow. It has been calculated that the total improvement from Chevalier to Spratt-Archer was equivalent to an increase in yield of 20% of grain of superior quality; and the success of Spratt-Archer and Plumage-Archer was such that by the early 1940's something like 80% of the barley acreage in England and Wales was sown to these two varieties.

The position of Spratt-Archer and Plumage-Archer, which had been so secure for something like twenty years, was threatened by two changes during the last war. The first of these, which is the change of considerably lesser importance, was the production in 1943 of the first winter-hardy malting barley by the hybridisation of Spratt-Archer with Tschermak's two-row winter barley. This new variety, named Pioneer, has continued to be grown as the only winter malting barley variety since its introduction, but it has never occupied a high percentage of the acreage (less than 10%) because new non-hardy varieties have come on the market, and these are risked by farmers as winter crops. The second, and more important development, was the arrival in Britain of the Danish varieties Kenia and Maja, which demonstrated during the war their capacity to give higher yields and to stand upright under intensive farming. These new varieties were also earlier maturing and they quickly showed that their field virtues for the grower tended to outweigh their deficiencies in malting quality and their greater susceptibility to Mildew and Loose Smut diseases. Indeed, so popular were these types among farmers that the whole character of English malting barleys began to change, in spite of the lower market value of the grain, and yields rose steadily (Table I).

The gradual swing over to the new types of barley is reflected by the figures in Table II which shows the percentages of each variety received at the Official Seed Testing Station, Cambridge. The demands of the farmer were obvious, but the maltsters and brewers still preferred the old English varieties. Consequently, breeders in this country set themselves the task of combining the virtues of the Kenia field type with the malting quality of Spratt-Archer and Plumage-Archer, and many hybrids were made which are illustrated schematically in Fig. 5. This programme of hybridisation has proved itself singularly successful, and during the last few years three new varieties—Proctor, Provost and Maythorpe—have been made available to growers in this country. Proctor, which is a hybrid between Plumage-Archer and

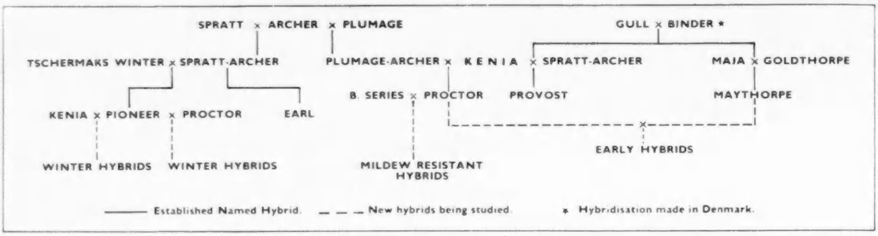
TABLE II

PERCENTAGE OCCURRENCE OF BARLEY VARIETIES

Variety	1939–40	1942–3	1945–6	1948–9	1950–1	1951–2	1952–3	1953–4	1954–5
Spratt-Archer	42·2	41·0	43·4	25·3	23·9	19·9	13·0	10·9	6·7
Plumage-Archer	28·8	33·4	26·6	21·1	24·2	18·0	13·5	11·7	7·1
Plumage	9·6	3·6	2·3	1·8	1·2	—	—	—	—
Golden Archer	5·0	3·6	3·4	1·7	1·3	—	—	—	—
Kenia	—	4·4	15·0	22·2	22·5	21·2	16·5	9·5	5·0
Pioneer	—	—	—	12·8	6·2	8·9	8·3	7·7	4·8
Earl	—	—	—	5·7	7·5	9·7	10·2	12·3	10·9
Freja	—	—	—	2·5	5·1	6·3	7·2	5·6	4·2
Carlsberg	—	—	—	—	—	4·0	15·5	19·1	11·4
Herta	—	—	—	—	—	—	8·0	13·4	14·9
Proctor	—	—	—	—	—	—	—	4·1	29·1

Figures showing percentage of each variety received at the Seed Testing Station, Cambridge.

FIGURE 5.



Kenia, was the first to be released and has spread so rapidly that it will probably be grown on nearly half the barley acreage in England and Wales in 1955. This is almost certainly an unprecedented rate of increase for a new cereal variety in this country. Proctor has outyielded its higher yielding parent (Kenia) by an average of 15% (Table III), while it has surpassed Spratt-Archer by as much as 30%. It has short, strong straw; high malting quality and satisfactory resistance to Loose Smut and Mildew: it is intermediate in ripening time between its two parents Kenia and Plumage-Archer. Provost, which is a hybrid of Kenia and Spratt-Archer, is a similar field type to Proctor, rather later in maturing, and gives rather lower yields of grain, while Maythorpe, which was derived from crossing Maja and Goldthorpe, is the earliest of the new hybrids, has a short straw, and a large grain with quality characters that are attractive to certain maltsters. (Figs. 1, 3, 4.)

These three varieties have set a new high standard in combining the best field characters with desirable malting and brewing characters, so that they have gone a considerable way in reconciling the requirements of grower and consumer. They will probably be instrumental in helping to eliminate the undesirable foreign varieties, while it seems probable that Spratt-Archer and Plumage-Archer will continue to decline in acreage. It should be mentioned, however, that the grower's demand for greater earliness was partly met by the marketing some ten years ago of an early selection of Spratt-Archer, named Earl, but the yield of this variety, being only equivalent to Spratt-Archer, does not reach the standard now required. It appears, also, that a variety like Proctor can meet the challenge of the more recent foreign introductions like Herta and Rika, which are very high yielding and have exceptionally strong straw. They are thus suited for growing as feeding barleys, but their susceptibility to diseases, and very poor malting quality grain, will limit their usefulness now Proctor is available.

But further improvement is always possible, and work is continuous in plant breeding. Intensive programmes of hybridisation are now in progress which have as their objective the production of varieties showing new combinations of desirable characters. Examples of these are the selection of higher yielding, stronger strawed and better quality winter-hardy forms; the combining of earlier ripening with high yield and good quality; and the addition of Mildew immunity to Proctor and other varieties.

There does, however, seem to be scope for exploiting another method of effecting genetic changes which will lead to improved varieties. It is possible to induce artificially sports or mutations by exposing the grain before sowing to irradiation by x-rays, fast neutrons or slow neutrons (Fig. 2). This method has certain obvious advantages over hybridisation in that it is possible to effect changes in single characters by one operation, and new true-breeding forms can be produced without the complications of hybridisation followed by years of selection necessary to isolate the desirable forms in a stable condition.

Investigations on these lines have progressed to the stage when earlier maturing and shorter straw forms of the variety Proctor are in small-scale field trials, while a wide range of artificially induced mutations in barley are being studied intensively in this country and in Sweden. Although the more obvious and easily induced barley mutations are now well known, there is still great scope for more delicate and better controlled methods for this means of producing new genetic variability of potentially valuable new forms. While some workers are concentrating more on trying to produce mutants of direct agricultural use, others are visualising the method as more suited to the production of breeding material that can be used subsequently in hybridisation programmes. Although there is considerable speculation on the ultimate possibilities of artificially induced mutations, and some scientists are talking in terms of reconstructing the morphology, anatomy and nuclear structure of barley by this means, it seems doubtful if the more extravagant flights of imagination are at present justified. Up to the present no new barley variety of economic worth has its origin as an artificially produced mutant, but this work is still young.

At the moment, however, no breeding technique can compete with hybridisation as a means of crop improvement, although there is still room for considerable improvement in the methods employed in the handling of hybrid populations and in raising the efficiency of selections. Selection on individual characters may be of an acceptably precise and accurate standard where methods of assay can be based on a test that is subject to reliable quantitative or qualitative analysis. But one of the major problems in plant-breeding is the devising of accurate methods for assessing the relative value of large numbers of individuals, or their offspring, when they differ in various combinations of complexly inherited quantitative characters. Genetic analysis is difficult at this level, but the economic value of a particular selection may depend entirely on a delicately balanced expression of such characters, and it is on a correct assessment that success in breeding depends.

MATTER AT LOW TEMPERATURES

PROF. G. O. JONES, M.A., B.Sc., Ph.D.

This is the second of three articles in which Prof. G. O. Jones, who is Professor of Physics at Queen Mary College, discusses the physics of extreme conditions. The first article appeared in our July issue. The theme of the final article, to be published next month, will be High Pressures and High Densities.

Sir Francis Simon has recently remarked that in the field of low temperatures "man has considerably surpassed Nature herself". It is true that temperatures occur in Nature which are lower than those ordinarily found on earth, but the lowest such temperature is still very high by the standards of the low-temperature physicist. For instance, most of the planets are much colder than the earth, and temperatures as low as about 10°K—that is, 10 degrees above the absolute zero—may exist on planetary surfaces facing away from the sun, as compared with about 273°K on a cold day on our earth. But 10°K is 10,000 times hotter than the lowest temperature achieved in the laboratory, about 0·001°K.

Indeed, until about ten years ago astronomy had no connexion with low temperatures, even of this moderate order. The reason is fairly simple; we obtain information from stars only by receiving the radiation which they emit. Knowing that the maximum amount of radiant energy which can be emitted by a surface is proportional to the fourth power of its absolute temperature, it is not surprising if little information of low-temperature interest has been received, even though it is known that much of interstellar matter is within a few degrees of absolute zero. One important observation has, however, been made. It had been forecast by the Dutch astronomer van de Hulst of Leiden Observatory that hydrogen in interstellar space would emit a characteristic radiation of 21 centimetres wavelength, and that this should be detectable even from hydrogen at very low temperature. This wavelength is within the range of the new science of radio-astronomy, and the study of this radiation has since proved to be a powerful method of determining the distribution of hydrogen—the main constituent of the universe—in various directions in space.

REACHING LOW TEMPERATURES

We have to return to the laboratory to find out about the behaviour of matter at low temperatures, and to find how man has been able to juggle with the laws of thermodynamics in order to reach these temperatures. Thermodynamic laws are certainly against him in one sense, for in creating "cold" where he wants it he must create at the same time a greater amount of heat elsewhere. In another sense, however, they are in his favour. As we see later, it turns out that as long as the properties of matter can be changed by lowering the temperature, then the changes can be made use of to reach the required temperature.

The general principles of reaching low temperatures are the same whether one is interested in refrigeration at only a few degrees below room temperature or in reaching temperatures near absolute zero. They can be illustrated by considering a very simple process: if a gas is compressed slowly so that the heat of compression—familiar to everyone who uses a bicycle pump—can get away, and it is then allowed to expand quickly, it becomes cooler. The essential features of the two parts of the process are not of course that they should be carried out slowly or quickly, but that the first part is carried out at constant temperature, or *isothermally*, and the second part is carried out in such a way that no heat can enter or leave the gas, that is, *adiabatically*. In practice, these requirements would probably be met by varying both the speed of the operation and the degree to which the gas was in thermal contact with, or isolated from, the surroundings.

We can see by considering Fig. 1 that this is an example of the general principle mentioned above, since the process depends upon the fact that the pressure and volume of a quantity of gas depend upon temperature. In Fig. 1*a* the two "isothermals" drawn represent the relationship between pressure and volume at two temperatures T_1 and T_2, T_1 being higher than T_2. At constant pressure the volume would be increased by raising the temperature, or at constant volume the pressure would be increased. (The whole behaviour is represented, for the so-called "ideal" gas, by the well-known "gas equation": $pV=RT$.) Intersecting these two curves is an "adiabatic", showing the relationship between pressure and volume when no heat is allowed to enter or leave the gas, for one particular set of starting conditions.

The way in which these variations can be used to lower the temperature is indicated by the thick line *ABC*. The gas, initially at point *A*, is first compressed "isothermally"; that is, the heat generated by the compression is dissipated into the surroundings and not allowed to raise the temperature of the gas. Now, at point *B*, the pressure is released "adiabatically". The result is that the temperature of the gas falls from T_1 to T_2.

Engineers are more familiar with the representation of such processes in another way, illustrated in Fig. 1*b*. Here the *entropy* of the gas is plotted against temperature for two different pressures. The entropy is one of the important thermodynamic properties (like the pressure, volume, or temperature) by which the condition of a system can be specified. Its importance for the physicist lies in the fact that it gives a measure of

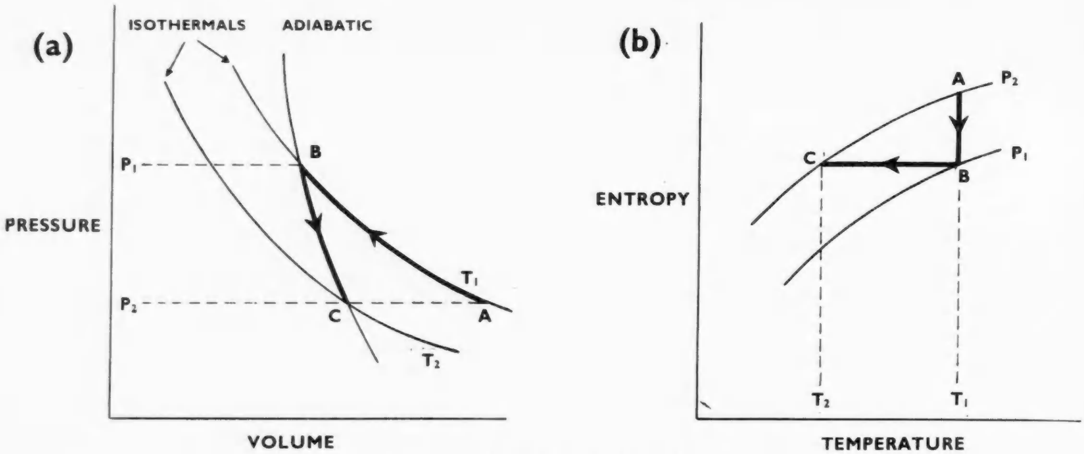


FIG. 1. General principles of refrigeration.

the degree of "disorder" of a system. For example, the entropy of a liquid just above the melting-point is always appreciably greater than that of the solid just below this temperature because of the much greater disorder in its atomic or molecular arrangement. In the same way, the curve of Fig. 1*b* shows that at a given pressure the disorder of a quantity of gas increases with increasing temperature—a very plausible result, even if it cannot so easily be given a simple explanation. As will be clear from these examples, there is a connexion between the entropy of a system and the quantity of heat which enters or leaves it during any process. Entropy remains constant during all adiabatic processes provided they are *reversible*; that is, provided the system is as nearly as possible at equilibrium at each stage of the process, having the "correct" volume or other characteristics corresponding to the particular pressure and temperature. The complete process is then represented very simply in this case by the two straight lines *ABC*.

Many readers will recognise the line *ABC* of Fig. 1*a* as part of a Carnot cycle, which has great significance in textbooks of thermodynamics because it provides the basis for setting up the "thermodynamic scale of temperature". They may suspect that this discussion is somewhat academic. Oddly enough, this is quite untrue; the method suggested by Fig. 1 has recently become very widely used for the liquefaction of helium, and the same general method applied in a different context forms the basis of the method of *adiabatic demagnetisation*, by which the lowest temperatures are reached.

THE LIQUEFACTION OF HELIUM

The importance to low-temperature physics of the liquefaction of gases, particularly helium, may be seen by consulting the chart of Fig. 2, in which the range of temperature of greatest interest has been suitably spread out by using an exponential scale. It will be seen that if one has liquefied helium the whole range of temperature down to 4°K may be covered at once. Actually, the temperature of liquid helium can easily be reduced to about 1°K by causing it to evaporate under reduced pressure. If one does not wish to reach such low temperatures it may be sufficient to liquefy hydrogen instead, or even to use liquid air or liquid nitrogen. When liquefied, these substances are ideally suited for the control of low-temperature apparatus near a desired temperature, because their latent heat of evaporation makes them into very compact reservoirs of "cold" which can be maintained at constant temperature simply by keeping the pressure constant.

A great deal of ingenuity has been devoted to the design of gas liquefiers for use at these very low temperatures, where the practical difficulties are somewhat more acute than in ordinary refrigeration. One of the most interesting helium liquefiers was that designed by the Russian physicist Kapitza which, installed at the Royal Society Mond Laboratory at Cambridge, performed heroic labour for many years in keeping the laboratory supplied with liquid helium. In effect, this liquefier uses the process illustrated in Fig. 1 combined with "regenerative cooling", in which the gas after expansion in a cylinder is passed through one limb of a heat-exchanger in order to pre-cool the incoming gas passing through the other limb. This is, in fact, the well-known Claude process, one of the two most important processes for the liquefaction of gases in general. In applying it to the case of helium the special difficulty is that no lubricant can be used in the cylinder (the expansion stroke must take place in the cylinder at very low temperature, though the gas is compressed elsewhere) because no other substance remains fluid down to liquid helium temperatures.

A liquefier of this type, built in Kapitza's Russian laboratory, is shown in Fig. 3. In Fig. 4 is shown a modern "streamlined" version of the same general type which is commercially available in the U.S.A. and has been largely responsible for the rapid growth of low-temperature studies in that country since the war. This

is the Collins helium liquefier, which makes use of superior engineering techniques and materials, and aims to make the liquefaction of helium a matter of laboratory routine rather than the feat of organisation which it has often been in the past.

There are of course many other kinds of helium liquefier, of which one important class makes use of a quite different process, usually known as the Linde process, which depends upon the cooling which a *non-ideal* gas suffers under favourable circumstances on being throttled through a valve. A non-ideal gas is, by definition, one which does not obey the gas equation $pV=RT$. Every gas is non-ideal to some extent, because of forces between its molecules, and in the Linde process the starting conditions are chosen so as to make use of this non-ideality in such a way as to cause cooling.

The special advantage of the Linde process is that a liquefier based on this principle does not require to have moving parts at very low temperatures and there are, therefore, no lubrication difficulties. It is an interesting fact that at about the time when the Collins version of the Kapitza liquefier was going into production in the United States, the Royal Society Mond Laboratory at Cambridge replaced their ageing Kapitza machine by a new helium liquefier of the Linde type.

At the most famous home of low-temperature physics, the Kamerlingh Onnes Laboratory at Leiden, the Linde process has been used generally, and it was here that Onnes first liquefied helium in 1908. At the Clarendon Laboratory, Oxford, both the Linde process and a special "one-stroke" expansion method (essentially of the Claude type) developed by Simon, have been used. A certain amount of friendly rivalry exists between low-temperature laboratories over the relative merits of their liquid helium facilities.

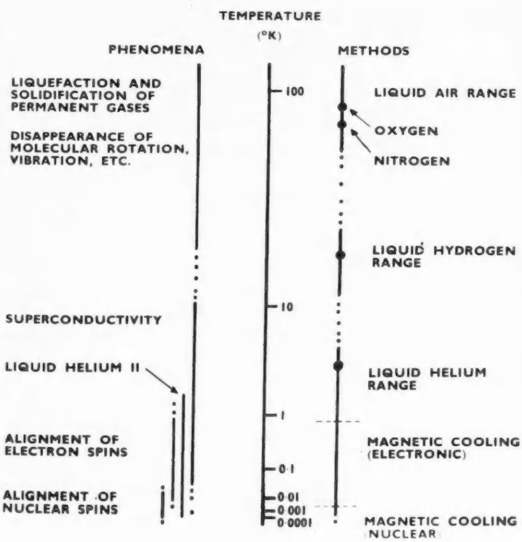


FIG. 2. Chart of low-temperature phenomena. (Based on a diagram printed in *Science Progress*, Jan. 1952.)

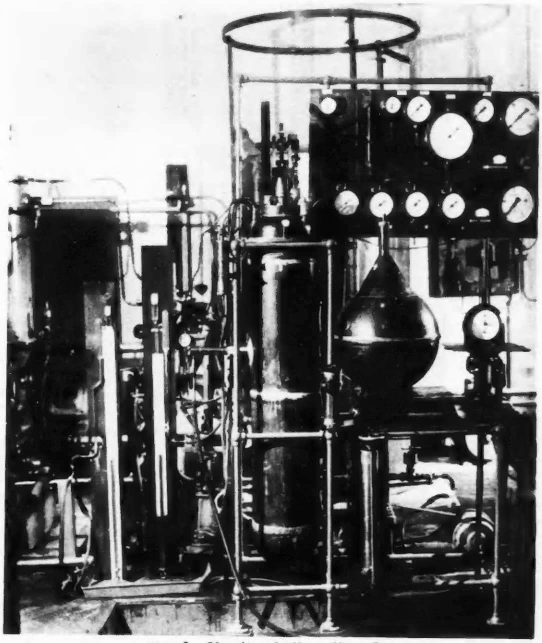


FIG. 3. Kapitza helium liquefier.

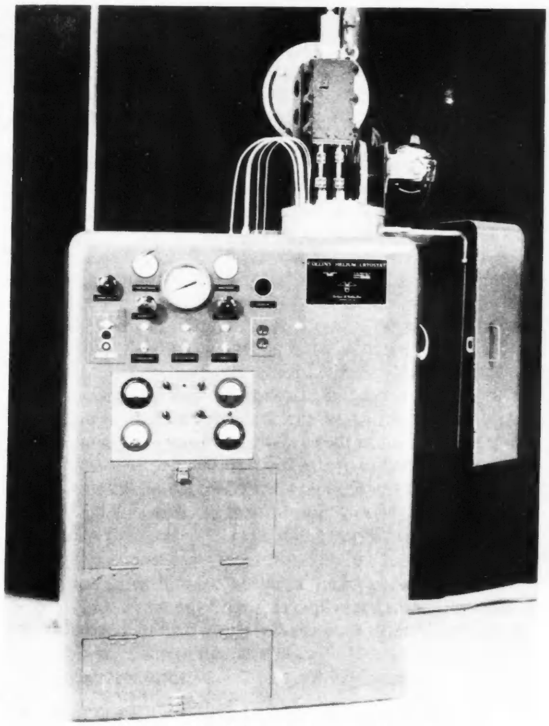


FIG. 4. Collins helium liquefier. (*Courtesy, A. D. Little Inc.*)

TABLE I. This exemplifies characteristic relationships between absolute temperature, energy per particle, and wavelength of electromagnetic radiation.

T = Temperature measured on the Kelvin absolute scale	ε = energy per particle measured in electron-volts.		λ (Wavelength in Angström units or centimetres)	
degrees K.				
10^{10}	10^{6}	binding energy per particle in atomic nuclei; energies of α-particles emitted in radio-activity.	10^{-2} A	*γ-rays*
10^{8}	10^{4}	atomic excitation energies in "deep" electron shells.	1 A	*X-rays*
10^{5}	10	atomic excitation (electronic) or ionisation energies.	10^{3} A	*ultra-violet*
10^{4}	1	chemical bond energies; latent heat of vaporisation of water.	10^{4} A	*infra-red*
10^{3}	10^{-1}	latent heat of fusion of water; spacing between energies of molecular vibrational levels.	10^{5} A	*far infra-red*
10	10^{-3}	latent heat of vaporisation of helium; zero-point-energy of helium; spacing between energies of molecular rotational levels.	10^{-1} cm.	*short micro-waves*
1	10^{-4}	spacing between energy levels corresponding to fine structure in optical spectra.	1 cm.	*micro-waves*
10^{-2}	10^{-6}	spacing between energy levels corresponding to hyperfine structure in optical spectra.	10^{2} cm.	*short radio waves*

LOW-TEMPERATURE PHYSICS

The early growth of interest in the behaviour of matter at low temperatures was concerned mainly with the phenomena named near the top of the chart of Fig. 2. The liquefaction and solidification of the last remaining "permanent gases" such as hydrogen, neon, helium, was first of interest. As was explained in my first article in discussing the general significance of temperature, it is possible to estimate roughly at what temperature a particular phenomenon will occur if one knows what energy is associated with it. If one is interested in a process which involves an amount of energy per particle ε, then something of interest will be expected in the neighbourhood of the temperature T, given by $T=\varepsilon/k$ (from the well-known equation $\varepsilon=kT$), where k is Boltzmann's constant. This is illustrated in Table I, taken from the first article, in which corresponding values of ε and T are listed, together with values of the wavelength of the corresponding electromagnetic radiation. Looking at the Table we see the permanent gases had remained "permanent" because only very weak attractive forces existed between their atoms or molecules; a very small energy would suffice to separate them. However, as lower and lower temperatures were reached in low-temperature laboratories, these gases were liquefied and solidified one by one, the last of course being helium. As illustrated in the Table, the latent heat of vaporisation of helium, which is a rough measure of the energy required to separate helium atoms, corresponds quite closely to its boiling-point, 4·2°K, when use is made of the formula $\varepsilon=kT$.

As low-temperature physics progressed, the greatest interest in the phenomena studied lay in the fact that they illustrated those features of the "quantum" behaviour of matter which were becoming increasingly understood since the first announcement by Planck of his *quantum theory* in 1900. This stated, in effect, that interchanges of energy take place not continuously but in *quanta* whose magnitude depends upon the type of particle involved. In its application to low-temperature physics its main importance lies in the fact that the particles in a gas or in a piece of solid distribute their energy—such as their vibrational, rotational or translational energy—not over a continuous range of values but over a series of discrete levels. It is the spacing of these energy levels which is of greatest interest. For we find that at temperatures well below that corresponding to a given spacing ε, no further change can be detected; the particles have settled down into the lowest "quantum state" possible in the given system. At temperatures well above that corresponding to ε the spacing is so close as compared with the total thermal energy that the existence of discrete levels hardly affects the behaviour, which returns to the so-called "classical" pattern. In between lie those changes which are studied by the low-temperature physicist.

One of the most important methods of finding out about the motions or vibrations in matter is to measure the *specific heat*, that is, the amount of heat required to raise the temperature of unit mass of the substance through one degree. Much of the early work in low-temperature physics consisted of determinations of specific heats down to as low a temperature as possible and it was shown that the allocation of energy to the various kinds of motion "died out" progressively. For example, in a gas consisting of diatomic molecules the vibrational motion of the molecules can be shown to die out first, then at much lower temperatures the rotational motion disappears also. It is important to understand that even in "classical physics" the energy associated with the motion of particles in matter is reduced by lowering the temperature. The special feature of quantum theory is that because the particles cannot adopt all values of energy but only discrete energy levels, the energy dies away much more rapidly at low temperatures.

In spite of the great importance of such matters to the physicist, they do not give rise to simple, visible, macroscopic effects. We now turn to discuss two unexpected phenomena discovered at low temperatures, which can be as fascinating to the non-specialist as they are still puzzling to the physicist—superconductivity and liquid helium II.

SUPERCONDUCTIVITY

Very many metals are found to lose their electrical resistance completely at sufficiently low temperatures. The disappearance of resistance occurs sharply at a

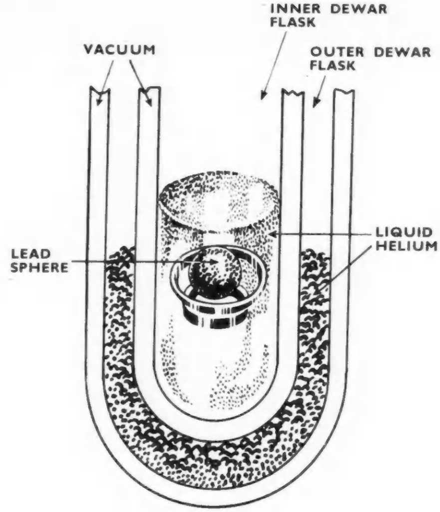


FIG. 5*a* (*left*). A lead sphere in the superconducting state supported by the magnetic forces due to persistent currents flowing in the sphere and in the pair of lead rings. FIG. 5*b* (*above*) clarifies the details of the experimental arrangement pictured in the photograph.

temperature which is characteristic of the particular metal. For lead, this characteristic temperature is 7·22° K, while for hafnium it is 0·35° K. The phenomenon is known as *superconductivity* and has engaged the concentrated attention of low-temperature physicists since its discovery by Kamerlingh Onnes at Leiden in 1911. The fact that superconductors really are perfect conductors of electricity can be demonstrated by causing electric currents to be started in, say, a ring of superconducting metal. The currents will then persist indefinitely. In Fig. 5 we see a lead sphere "floating" above lead rings because of the magnetic action of persistent currents which have been started in the rings and the sphere. The photograph illustrates also some rather typical features of low-temperature apparatus; the lead sphere and rings are immersed in liquid helium, contained in a sort of "Thermos flask" (unsilvered in this case) which is surrounded for protection by another vessel containing refrigerant, probably liquid helium again, but in this vessel boiling vigorously because of the heat influx from the surroundings.

There is no prospect of using the property of superconductivity for the technical purpose of transmitting electrical power without loss, because the effort required to produce and maintain the necessary low temperature against the inevitable heat influx would be quite prohibitive. There are, however, a number of interesting ways of making use of superconductivity for very specialised purposes, particularly in the design of other experiments. One such type of application is suggested by Fig. 5, for the lead sphere is, so to speak, held in a "frictionless mounting". Other applications make use of the lack of resistance more directly, and these have included devices for the detection and measurement of very small electrical voltages, or of very small flux of thermal radiation. In spite of the necessity for maintaining the effective part of the device at very low temperature, serious attempts have been made to use such devices for the development of alternatives to radar, because of their great sensitivity.

Superconductivity is recognised as a "quantum" phenomenon even though it is not yet properly understood. The application of quantum theory to the general problem of ordinary electrical conduction, which had been brilliantly successful, had entirely failed to account for superconductivity. Quite recently, however, physicists have begun to think that they understand its origin. I shall not try to develop the argument except to say that it depends upon a newly discovered mechanism which would give rise to a minute force between the "loose" electrons in metals which are responsible for the ordinary conduction of electricity. In a special sense these might then "condense" at a sufficiently low temperature.

LIQUID HELIUM II

Helium is very unusual in its properties in many respects. First, it exists in liquid form down to the absolute zero; only under a pressure of about 25 atmospheres can the solid form exist at all. Of course, the absolute zero has not been reached in any experiment,

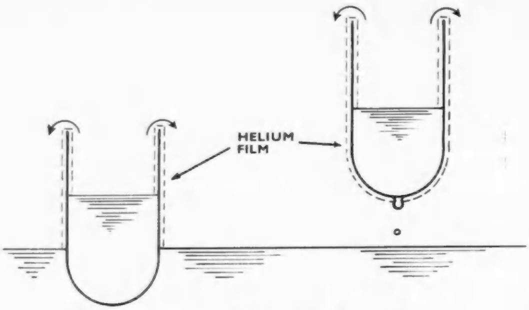


FIG. 6. Flow in the helium film.

but it is obvious from the behaviour of liquid helium at temperatures within a few hundredths of a degree of zero that it will not solidify except under pressure, however low the temperature. Now the existence of a liquid at absolute zero is in itself unexpected because it is a law of thermodynamics that any system which is able to reach equilibrium at absolute zero must become perfectly ordered. We are familiar with the general tendency towards ordering in the change from gas to liquid and then to solid as the temperature is lowered. An ideal gas is highly disordered; a liquid is only ordered in arrangement for a small range around each atom, but an ideal crystalline solid is perfectly ordered, with its atoms spaced regularly in a lattice.

However, when viewed according to modern quantum ideas, it appears that liquid helium at 0°K may also be perfectly ordered, but in a quite different way. Here the order lies in the velocities, not in the positions of the atoms: an irregular stream of traffic, but one in which all the vehicles moved at the same speed, would be an analogous situation.

Secondly, the properties of liquid helium itself are unusual. Below 2·19°K it shows a complete change of behaviour; it is here given the name liquid helium II, the term liquid helium I being reserved for the normal liquid above 2·19°K. The main change is that the resistance to flow, or the viscosity, now disappears entirely. This gives rise to many curious macroscopic effects, some of which are associated with another property of helium at these low temperatures, its habit of forming a film, of the order of a hundred atomic diameters in thickness, on any solid surface. One of the best-known effects shown by liquid helium II is illustrated in Fig. 6. If a beaker containing liquid helium II and partly immersed in it is lifted a little out of the liquid, the level in the beaker will be found to fall because of a sort of "siphon" effect in the film. If the beaker is lifted right out of the liquid, liquid helium will climb out and drop off at the lowest part of the beaker just as if there were a hole in it at this point.

As might be expected, some of these effects are quite embarrassing to the experimenter who is trying to study liquid helium II. A good deal of information about its properties has, however, been obtained, and this is perhaps at least equally embarrassing to the theoretician. These are among the most interesting and puzzling topics in low-temperature physics at present. The differing behaviour of the helium isotope of mass 3 (instead of 4 as in the common isotope), which is available as a by-product in certain nuclear processes, is of special theoretical interest because, from the point of view of quantum mechanics, the two isotopes are expected to obey quite different statistical laws.

The term "superfluidity" is often used in referring to the absence of viscosity in liquid helium II, and the liquid itself is called a "superfluid". Indeed, among low-temperature physicists the term superfluid is often used to cover both superconductivity and liquid helium II. In spite of uncertainty about the theoretical implications of the comparison, there are many analogies between the two sets of phenomena. In liquid helium II again some sort of "quantum" condensation is presumed to occur, the participants now being helium atoms instead of electrons. Some writers have been so impressed with the strange properties of the superfluids that they have described them as characteristic of a new "state of aggregation".

THE LOWEST TEMPERATURES

Although no other obvious macroscopic changes occur as matter is cooled to lower and lower temperatures, there are certain changes associated with the "fine structure" of crystals, particularly in respect of the orientation, from the magnetic point of view, of certain of the electrons in the structure. Behaving as elementary magnets, they have the possibility of becoming ordered —in this case of becoming parallel—at sufficiently low temperatures. The quantum energy levels associated with different orientations of these electronic magnets are so close that only at temperatures below about 1°K does this ordering begin to set in. These energy spacings are also associated with the "fine structure" in optical spectra, and we see from Table I that something of interest should therefore be expected near about 1°K.

Now as already suggested, the existence of any such effect can be made use of to lower the temperature, and the method is illustrated in Fig. 7. Just as in Fig. 1*b*, entropy is plotted against temperature; the specimen is now not a gas but a paramagnetic crystal, that is, a crystal in which there is no spontaneous alignment of the elementary electronic magnets but in which alignment can occur under the action of an applied magnetic field. As will be seen, the application of a magnetic field lowers the entropy at a given temperature, because it lowers the *disorder* by aligning the elementary magnets.

By following the path *ABC*, a cooling from, say 1°K to 0·01°K can easily be effected in one step *via* an *adiabatic demagnetisation*. The process is as follows: after cooling to about 1°K, using liquid helium, a strong magnetic field is applied by a powerful electromagnet. The heat generated (analogous to the heat of compression in the bicycle pump) is allowed to dissipate. Then the magnetic field is switched off and the sudden cooling takes place.

By performing two such steps, temperatures as low as 0·001°K have been reached. The main phenomena

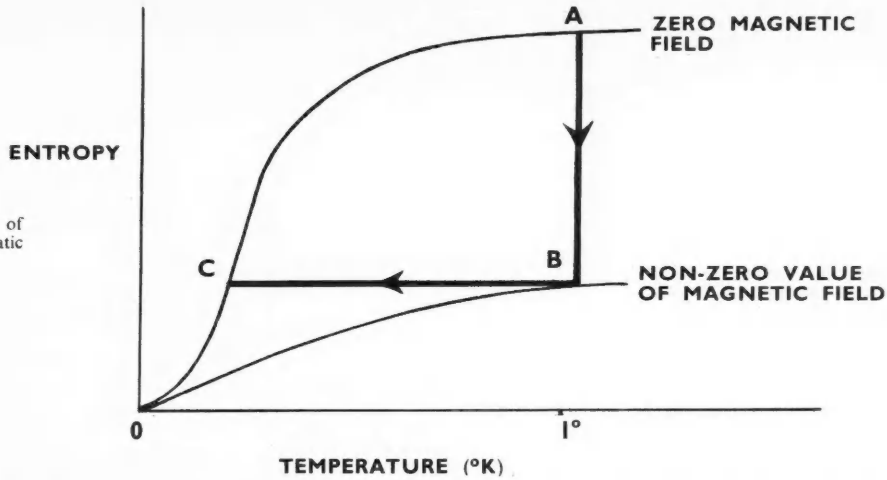


FIG. 7. The principle of the process of adiabatic magnetisation.

which can be studied in this range are those associated with the magnetic fine structure itself, and a great deal of information in this rather specialised field has now been obtained. Certain other experiments can be carried out at these, the lowest temperatures yet reached, by mixing the substance to be studied with the powdered paramagnetic crystal. The experimental difficulties are serious, but of course they only serve as a stimulant to the physicist.

The reader may wonder whether this is the last step. Can still lower temperatures be reached—and can the absolute zero of temperature itself be reached? It appears that the answer to the latter part of the question is that no experiment will ever reach 0°K but that it is possible in principle (even though experimental difficulties will rapidly become forbidding) to approach zero as closely as desired. The verdict of quantum theory, after studying the results of low-temperature studies in general, is that whatever ordering process is considered, the curve of entropy against temperature will always approach the origin more or less in the way illustrated in Fig. 7. Very near the origin the slope of this curve must become zero. It is then easy to see why, by going through a series of steps of the type *ABC*, it will be possible in principle to approach zero temperature as closely as desired, but never to reach it.

Finally, we come to one important topic of present interest in low-temperature physics which may ultimately lead to the attainment of still lower temperatures. At the foot of Table I are mentioned certain very closely spaced energy levels associated with the hyperfine structure in optical spectra. These correspond to different orientations, again from the magnetic point of view, of atomic *nuclei*. These elementary magnets are still weaker than those associated with electrons, and a still smaller amount of thermal energy is sufficient to disorientate them. If the experimental difficulties can be overcome, one can imagine further processes of the type illustrated in Fig. 7, but probably *starting* at the temperatures attainable by the electronic demagnetisation process, in which the nuclear demagnetisation may lower the temperature perhaps to one-millionth of a degree.

We can now appreciate more fully the significance of one of the first topics mentioned in this article. For the emission of the 21-centimetre radiation by hydrogen in interstellar space is caused when the electron and the nucleus (or proton) of a hydrogen atom change their relative *magnetic* orientations. The "characteristic temperature" of this change (see Table I) would be about 1/20°K; that is, only at temperatures well below this would all hydrogen atoms settle down into their most ordered state. Although this is not, strictly, one of the topics studied by the low-temperature physicist, it affords an example of the way in which the study of matter can be approached from many directions. As a matter of fact, the whole approach of low-temperature physics has somewhat shifted since the war, because the development of very short-wave radio techniques (used in radar etc.) has allowed many of the processes mentioned near the bottom of Table I to be studied more directly by observing the absorption or emission of radiation caused by jumps between quantum levels.

FURTHER READING

Two useful books on this subject are: F. E. Simon et al., *Low Temperature Physics*, Pergamon Press, London, 1952; L. C. Jackson, *Low Temperature Physics*, Methuen, London, 2nd edition, 1955.

ARCHAEOPTERYX AND THE EVOLUTION OF FLIGHT

W. E. SWINTON, Ph.D., F.R.S.E.

Among the histories that have been partly unravelled none is more intriguing than that of the birds. The enormous variety of present-day species rapidly decreases as we go back in geological time and by the early part of the Eocene, about 60 million years ago, the remains of fossil birds are comparatively rare.

Further back, in the Cretaceous period, there are only eight representatives; all of these are untypical of modern forms, and some of them only sketchily known. By far the best preserved are *Hesperornis,* which was a swimming bird with degenerate wings, and *Ichthyornis,* a small flying bird, whose remains were discovered in the Niobrara Chalk of North America.

Both of these show many features of the modern birds; for instance, we know that they had well-feathered wings, and a short tail, and hollow, pneumatic bones. In their separate ways they represent distinct stages in the evolution of flight. *Ichthyornis,* no larger than a pigeon, had a great keel on its breastbone, indicating strong muscular powers of flight. *Hesperornis* had no keel on its sternum and there are indications that it had abandoned flight for the ease of a life in the water. Both birds had well-developed teeth in their jaws, a feature unknown in all later kinds of birds.

In England we have a few remains of a bird of about this geological age, but these are not very illuminating. In 1864 the remains of a Cretaceous bird "about the size of a woodcock" were collected from the Cambridge Greensand and this fossil animal was subsequently named *Enaliornis barretti.* None of these fossils tells us much except that flight was already old, and that the beginning stages of its development must be sought in older deposits.

Now, below the Chalk there are great strata that have produced an abundance of fossils, mainly of the invertebrate animals that lived in the sea. However, as the main development of flight must have been accomplished over the land and as the bodies of the dead could not have laid for long undisturbed on the ground or on the forest floor, the search for the ancestors of birds in these pre-Cretaceous rocks is bound to be relatively disappointing.

Great deposits of a very fine-grained limestone that had been accumulated in a quiet and shallow inland sea during the Kimmeridgian stage of the Jurrassic Period occur in Germany, at Solenhofen in Thuringia. This stone was at one time extensively quarried for lithographic purposes, and was therefore worked with care and meticulously examined for quality. In this way its fossil contents rarely escaped detection. As the man who was local State doctor was an assiduous collector, a splendid series of fossils, especially of fishes and Pterodactyls, became known around 1860.

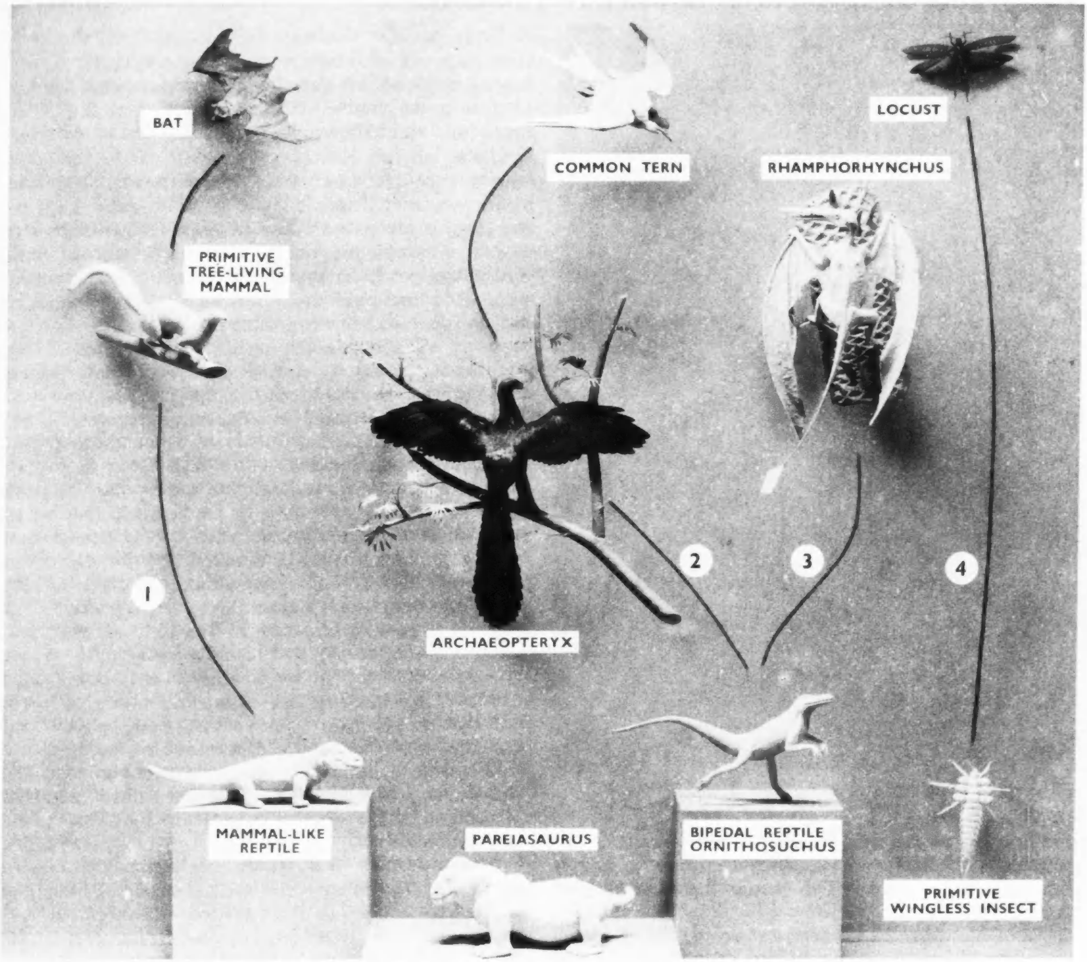
Most of these fossils were discovered on splitting the rock and were thus often represented on both sides of the split slab. Early in 1861 the workmen were surprised to find in this way the imprints of a feather, and soon they were astonished to obtain "the almost complete skeleton of an animal bedecked with feathers". This was found at Langenaltheimer Haardt, near the village of Pappenheim, where the doctor, Ernst Häberlein, lived. He quickly acquired the two slabs on which this specimen was displayed for his collection, and very shortly afterwards it was named by Hermann von Meyer as *Archaeopteryx lithographica,* which may be translated as "the ancient wing of the lithographic stone". The feather previously found was recognised to be from another specimen of *Archaeopteryx.* What sort of animal was this? It is clear that it was something of a puzzle to the workmen. They were used to Pterodactyls with their slender, delicate and hollow bones, and here apparently they were dealing with the remains of a reptile, with a reptilian head and with teeth in its jaws. The skeleton, too, seemed to be reptilian, but there were undoubted feathered wings attached to the arms. To complete the puzzle there was the well-marked impression of a long and feathered tail of a kind quite unknown among modern birds.

The preservation of the bones was good though not all of them were there and a few were fractured or displaced, but to the scientific eye there could be no doubt about the whole: it was a bird, the earliest that had ever been discovered.

Its fame soon spread and it was natural that the British Museum should want to add this rare specimen to its collection. There were difficulties, even in those days, about raising the money for the purpose. None the less the subject was pursued, and before the end of 1862 the specimen, with a representative collection of other things from Dr. Häberlein's collection, came to London for a total expenditure of £700.

In 1877 another and rather better preserved specimen of *Archaeopteryx* was found in a quarry, about ten miles from the first, at Blumenberg, near Eichstätt. This specimen was bought by the Berlin Natural History Museum for £1000.

Since then many persons have studied these fossils and have tried to unravel from them the early history of bird flight. Some investigators have even gone so far as to maintain that the flying birds stemmed from the Berlin specimen, and the flightless birds from the London specimen, which is stretching the long arm of coincidence rather too far. In all, some thirty-six attempts have been made by scientists to assess the systematic place of *Archaeopteryx.* About a year ago Sir Gavin de Beer, Director of the British Museum (Natural History), published what is by far the most comprehensive and detailed survey of the bird and its

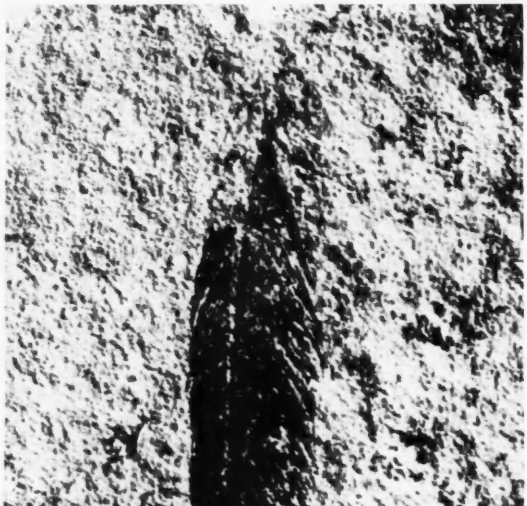


THE HISTORY OF FLIGHT: an illustration based on a photograph of the display case in the Bird Gallery of the Natural History Museum at South Kensington. Four evolutionary lines leading the emergence of flight are depicted: of the third line shown here, no living representative has survived. Line 1 begins with the reptile *Pareiasaurus*, from which evolved mammal-like reptiles like *Cynognathus*; between these ancestors of the mammals and the modern bats came primitive tree-living mammals (e.g. *Zalambdalestes*) which are now extinct. Both the birds and the flying reptile *Rhamphorhynchus* evolved, from reptiles (e.g. *Ornithosuchus*) that could run on two legs. In the fourth line, the locust is shown as deriving from a primitive wingless insect which lived about 300 million years ago.

relationships. His report is splendidly illustrated so that it will long remain a major source of information on *Archaeopteryx*. Here are recorded the results of his successful reinvestigation of the fossil material which involved the use of new methods. The use of ultra-violet light proved of tremendous assistance in resolving the character of many suspected markings on the slab, for in such light bone reacts quite differently from other substances. The use of indirect illumination, which brings the contours of bones into relief, was also one of the tricks employed to obtain quite startlingly clear photographs. *Archaeopteryx* had already been looked at with x-rays in 1916, but Sir Gavin de Beer insisted on a full examination by the latest equipment. In this way, while it cannot be claimed that a great deal of new material has been uncovered, the clear recognition of doubtful elements has been possible and new interpretations of the whole structure can now legitimately be made.

There are, for example, more bones of the skull on the slab of the London specimen than had hitherto been recognised and the apparently formless lump on the slab that represents a cast of the endocranial region has allowed an estimation of the structure of the brain to be made. From this it is interesting to learn that this primitive bird had a brain built on the reptilian, rather than the avian, plan.

The structure of the backbone has also been clarified



Archaeopteryx lithographica. The feather found first and now in the Munich Museum.

and it can now be definitely said that the ends of the vertebrae are flattened (*amphiplatyan*) or very slightly cupped (*amphicoelous*). This means that they too are of reptilian type.

The limbs were already well known, though it should be recalled how large the arms are in comparison with the hind legs. Perhaps the principal product of the new study is the discovery (or at least the rediscovery) that the sternum or breastbone is a boat-shaped piece of bone showing not the slightest trace of any keel or swelling that would indicate the attachment of strong muscles for a flapping kind of motion. In other words, we have now the best of reasons for supposing that *Archaeopteryx* was not a flying bird in the real sense but was a glider. As the plumage has now been especially well reconstructed, it is now possible to examine the whole principles of early avian flight and to speculate with some hope of success upon the direction of preceding and subsequent bird evolution.

Firstly, it is necessary to distinguish between those characters of *Archaeopteryx* which are reptilian and those which are avian. The bird characters are the feathers; the furcula (or merrythought); the opposable first toe of the foot; and the backwardly directed pubic bone in the hip-girdle. The truly reptilian characters are the non-hollow and non-pneumatic bones; the shape and method of articulation of the vertebrae; the long tail composed of twenty vertebrae; the length and size relationships of the fore-limb as compared with the hind-limb; the presence of claws on all three fingers of the hand, and, above all, the persistence of teeth in the jaws.

What are the conclusions to be drawn about the systematic and historical place of these early birds in the story of evolution? The answer Sir Gavin gives is that this mosaic of mixed characters indicates that *Archaeopteryx* is half-way between reptiles and birds. That does not quite mean that 50% of the characters are bird-like and the rest reptilian, but rather that the features which the comparative anatomist regards as significant are almost equally placed. Without doubt, the birds are descended from a reptilian ancestor.

Common sense tells us that *Archaeopteryx* cannot have been descended from a contemporary reptile, so that the problem becomes the search for an earlier reptile whose skeletal characters would seem to permit a gradual alteration to the features that occur in *Archaeopteryx* and whose mode of life would seem to give promise of such a development. In *Archaeopteryx* we can say that in evolution, as distinct from time, no really great advance had been made in the *skeleton* from a reptilian stage. The bird was small, no larger than a raven, so we may look for a reptile ancestor about a foot long, with a small skull which has teeth like those of *Archaeopteryx*, whose vertebrae had flattened or very slightly cupped ends, whose front limb was approximately the same size as the hind, and whose thigh-bone length was almost three-quarters the size of the lower hind leg. This last ratio is a matter of some importance in assessing the mode of movement of the animal.

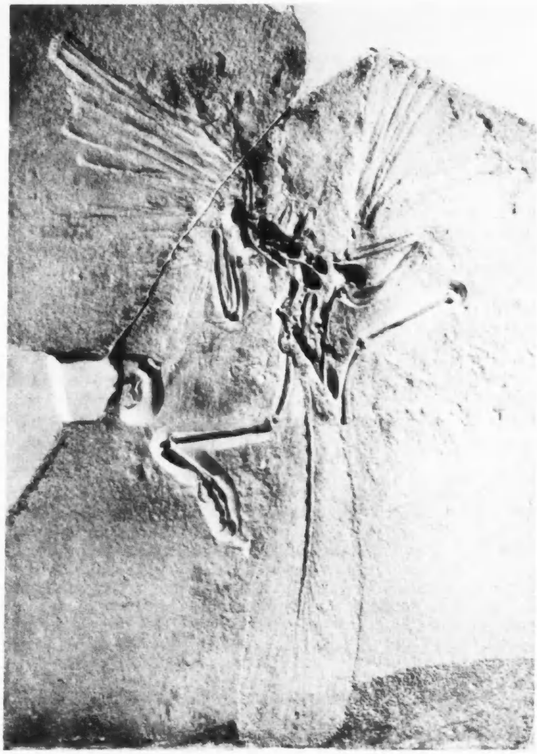
Now all these features can be found in varying degrees of agreement in two great groups of reptiles: the flying reptiles, or Pterodactyls, which shared very much the same environment as *Archaeopteryx* but whose method of flight was quite dissimilar and which had hollow bones, like modern birds; and the smaller bipedal Dinosaurs which could run on their hind legs with the forearms well away from the ground, and which have many characters in their skull, limbs and especially in the hip region, that are much like those of the earliest birds. But all this does not necessarily imply the descent of the birds from such reptiles, but rather that all of them were descended from a common ancestor.

As a result of such studies many people think that the common ancestor comes from a group of small reptiles, of bipedal habits, that are known from Germany, Scotland and South Africa. They are called the Pseudosuchia. Though I do not myself think that one of the Pseudosuchia was this common ancestor, the evolutionary stages are not too difficult to envisage.

Back in the Permian geological period, about 200 million years ago, there were apparently numerous kinds of small unspecialised reptiles with the ability of running on the hind legs, and thus of raising the front

parts of their body from the ground. We may conclude that in some geographical conditions there was a certain amount of overcrowding among populations of this kind and the fight for living-space may have been considerable. Some may as a consequence have been attracted to the trees. They already had the ability to balance on their hind legs, and this would be an asset in running along boughs. Once there, they would find a hitherto largely untapped source of insect and plant foods, so that the animal would be encouraged to climb the branches, wander from branch to branch and ultimately to leap from stem to stem. This would inevitably result in the development of the fore limbs into important organs for grasping and balance. The new kind of food would probably also lead to the reduction of the number of the teeth (as in fact has happened in *Archaeopteryx*). The next step—the gradual development of a branch jumper into a glider from tree to tree and the gradual growth of feathers—was probably quite accidental, though there is absolutely no fossil evidence to show how the feather first came into existence.

A few theories exist about the gradual fraying of reptilian scales to make feathers, but no credence can be given to them for a number of important reasons. The contemporary and distantly related Pterodactyls flew by means of a thin web of skin—a patagium—attached between the body and the forearm and hand, and these reptiles seem to have lost their scales, so that the process may be related to a heat-regulation mechanism associated with a good blood supply to a thin and unscaly skin. The primitive bird-ancestor may have attained a somewhat similar condition to begin with, though the well-developed flight of the Pterodactyls made them much freer of the air than even *Archaeopteryx* and, with much of their life spent over the sea or on rocky ledges, they may have needed a mechanism of this kind, whereas *Archaeopteryx* in the confines of the forest had a very different and less mechanical kind of flight. The close arrangement of the vegetation and their bough-hopping or gliding habits did not demand the same kind of superficial mechanism and the keratin covering of the forearms was perhaps some kind of answer. It would almost certainly add to the gliding potentialities. But their long hind limbs, the long tail, the flattened vertebrae all made true flapping flight, as we know it, difficult, though I believe that it was this very instability that was to lead to the development of true flight and the avian backbone and short tufted tail. The essay of an animal into the air demanded a great deal of perception and a high skill in balance, to which their arboreal experience had already contributed. The selective effect of these requirements was ultimately responsible for the increase in the size of the eye and orbit and of the brain. The stimulus for flight was the new supply of insect food; in order to catch such food there would need to be a lengthening of the jaws, and with such feeding habits there could be associated the loss of teeth (no longer needed) and the slightly different means of jaw movement leading to snapping ability. These are precisely the changes we find to have taken place in the step from reptilian skull to the *Archaeopteryx* head and jaws.



The skeleton of *Archaeopteryx lithographica* in the Natural History Museum. The skeleton is preserved on two slabs, this being the major portion.

None the less the stages of evolution we can observe in fossils have to be assumed from the skeletal evidence alone, and although it is true that a knowledge of comparative anatomy often suggests physiological probabilities we have not yet any real knowledge of the way of estimating their relative proportions. It would indeed be extraordinary if out of the vast range of Mesozoic time, the exact half-way stage of the reptile-bird transition had been discovered. It would have been a miracle. Yet the triumph of this recent work on *Archaeopteryx* is that we do not need to deplore the absence of all the ancestral materials. The discussion of the characters of the British Museum specimen, added to the deductions made from the studies on the Berlin specimen, clearly points the way in which avian development took place in the distant past and emphasises the fact that these first indications of the birds are among the most notable fossil milestones in the world.

The title of Sir Gavin de Beer's monograph mentioned on the first page of this article is Archaeopteryx lithographica. *The photographs illustrating this article are reproduced by courtesy of the Director and Trustees of the British Museum (Natural History).*

THE BOOKSHELF

A Guide Book to Electricity

By J. H. M. Sykes (*London, Hutchinson's Scientific & Technical Publications, 1955, 275 pp., 21s.*)

The difficult problem of presenting a scientific subject to the non-scientific reader offers a perpetual challenge which never goes long unaccepted. Experience tends to show that, for the most part new attempts are disappointingly like the old. Here, however, is a book in the "popular" class which is somewhat out of the ordinary.

It has been written "for the layman interested in electrical matters and perhaps also for those who—engaged in the other engineering arts may need some slight acquaintance with electricity".

After an initial chapter on basic principles, fairly detailed attention is given to the generation of electricity by electromagnetic machines, to prime movers and to the available sources of energy. Then follow eleven chapters dealing with the applications of electrical energy and the means by which these applications are affected. The examples of systems, machines and apparatus have been well chosen and are accompanied by practical data which should convey to the reader a sense of reality. Principles and phenomena are, for the most part, described as they arise in relation to the machines or other devices utilising them, and there are thus interspersed throughout the book passages dealing with fundamental matters. The range of topics covers all the major applications of electricity, namely the production of mechanical power, lighting, heating, telecommunication and electro-chemistry. There is, however, no section devoted to radiology.

The notable quality of this book does not lie in its scope or in the method of treatment of fundamentals which, indeed, in many respects, is open to criticism, but rather in the width and maturity of outlook with which the whole subject is presented. In the chapter on electricity supply, for example, there is a brief history of the establishment of the National Grid and of the subsequent developments leading to the setting up of the present Central Electricity Authority and Area Boards, together with a short statement of the structure and function of these bodies. In the same chapter there is a section on electrical risks. The following extracts taken from this chapter will serve to illustrate how the author, by what are often little more than brief asides, sets his technological material in its wider background. "There is no law which prevents a person from establishing his own private generating plant, but he must not sell electricity to anyone else." ". . . there is no law that specifies how an ordinary householder must conduct his own electrical affairs; but his insurance policy may well be invalidated if he installs unsafe electrical equipment in his home".

The factual information in regard to practice is accurate and thoroughly up-to-date. There are references, for example, to high voltage d.c. transmission, to air-blast circuit breakers, to fuel cells, to electrostatic ignition systems for cars and to submerged repeaters for submarine telephone cables, as well as to such much-publicised developments as nuclear power stations.

The illustrations are a particularly satisfactory feature of the book, the diagrams having been devised and drawn so as to convey a remarkably large amount of information.

In the presentation of *fundamentals* the book has, in the present reviewer's opinion, many deficiences. The author states in the preface that he has taken liberties in the interest of simplification. Such liberties are inevitable and need no apology, but there is great virtue in striving to present as accurate a picture as possible and in avoiding statements or analogies which may be misleading. The introductory section of the chapter on radio and television deals with electromagnetic radiation in a manner which seems unnecessarily obscure. There are throughout the book examples of analogies which might well confuse rather than enlighten, and of inaccurate statements which might lead to misunderstanding. On p. 128, for example, occurs the following sentence: "The impedance of a choke coil varies with the current which flows through it; the greater the current the more the impedance it offers."

Notwithstanding these defects, the book gives a most interestingly written account of the way in which electricity plays its important part in the life of the community today.

JAMES GREIG

Analysis of Development

By B. H. Willier, Paul A. Weiss and Viktor Hamburger (*Philadelphia and London, W. B. Saunders, 1955, 735 pp., 105s.*)

This is a solid satisfying sort of book for a biologist to possess. In it, some thirty well-known figures have reviewed important work in their many different fields, and, so far as one can judge such a wide spread of modern research, they seem to have done it very well.

Nevertheless, as one works one's way through the 735 pages one feels a certain sense of disappointment. One is not getting all one hoped for. For though the introduction expresses a modest hope that the book will be synthetic rather than encyclopaedic, the syntheses, except here and there and on the most limited of scales, refuse to emerge. Knowledge comes but wisdom lingers.

Perhaps one would mind this less if it weren't that the first two chapters by Jane Oppenheimer examine rather competently the history of methods and ideas in embryology, to see what may be learnt from the past that may help in the future. Dr. Oppenheimer concludes, wisely enough, that those who looked at embryos and asked the right questions were the ones who advanced the subject—Aristotle, Wolff, von Baer, Roux and Spemann, while those who started from preconceived, often metaphysical ideas, and only looked at embryos afterwards—Goethe, Haeckel and Driesch—held up the advance. She asks what are today's delaying theories, and makes the painful point that almost every embryological discovery that matters could technically have been made long before it was.

But this said, we come to a sharp discontinuity. The writers that follow seem for the most part to be less concerned to wonder what are the questions to be asked or the preconceptions to be discarded, than to cultivate intensively their own potato patches. Perhaps this is inevitable when a series of experts write about their own fields. But they might have ventured a little further, and one would like to have seen some of the later writers discussing their problems of organogenesis or differentiation in terms of the physics and chemistry and cytology that comes earlier. One would have liked, in particular, more from Tyler, who contributes two excellent chapters on Fertilisation, and the Ontogeny of Immunological Problems, and seems to come nearer to spanning the gap than most.

Perhaps criticism on these lines only amounts to saying that a large book, contributed by a lot of different people, cannot present a coherent synthesis of anything. It is certainly true that much slighter books than this, say Needham's *Order and Life*, or even Bonner's *Morphogenesis*, contrive to be more exciting. The mere facts in *Analysis of Development* have, after all, been reviewed often enough before, in many cases by the same contributors. And though collecting the facts within one cover is abundantly useful, it does not make for stimulating new ideas.

Perhaps it is high time that more embryologists wrote whole books themselves. One cannot help feeling that if five of the contributors to *Analysis of Development* had written five books of one-fifth the length, we should have been better off.

However, it would be unfair, and quite unjustified, to end up with criticism. *Analysis of Development* is a most useful book that will be valuable to a lot of people. It does, it is true, contain a few thin patches, particularly in the section on nucleus and cytoplasm

which leaves out much modern work on micro-organisms. But by and large, it is an exceedingly competent mammoth review. And if, as is likely, it encourages more of those who must now be called classical embryologists to draw on knowledge at the molecular and cellular levels, it will produce some most valuable cross-fertilisations.

MICHAEL SWANN

Photosynthesis

By Robert Hill and C. P. Whittingham (*London, Methuen; New York, John Wiley & Sons; 1955, 165 pp., 8s. 6d.: a Methuen Biochemical Monograph*)

Photosynthesis is the most important chemical reaction which takes place on earth both because of its size and the absolute dependence of the living kingdom upon it, and it is attracting more and more attention owing to recent discoveries made possible by techniques involving isotopic tracers, chromatography and coupled enzyme systems. However, in spite of the tremendous increase in our understanding of photosynthesis during the last decade or two, there are no books, both cheap and up-to-date, catering for the scientist not actively engaged in the subject.

This timely volume in the series of Methuen Monographs on Biochemical Subjects condenses all the salient facts of the anatomy, physiology, chemistry and physics of photosynthesis into some 150 small pages. It can be read in an evening or two, and it is possible to get an excellent introductory knowledge of the subject from it. It is not for the layman, however, as some knowledge of biochemistry is necessary for its comprehension, and it will find its public mainly among students and professional scientists. It will be of use as a pocket reference work too, owing to its conciseness, wide range and considerable factual content.

It has been established of recent years that photosynthetic tissue utilises energy from sunlight to split water molecules into oxidising and reducing potentials which respectively produce gaseous oxygen on the one hand and organic compounds by reducing carbon dioxide on the other. The senior author of this monograph, Dr. Hill, has himself played a considerable part in the development of our knowledge of the role of light in photosynthesis—indeed, owing to his research into the production of oxygen from water by illuminated chloroplasts (microscopic bodies which contain chlorophyll) isolated from photosynthetic tissue, this fundamentally important process is generally known as "the Hill reaction". Within the last decade the use of radioactive carbon together with paper partition chromatography has elucidated the various complicated reactions which occur during the fixation and reduction of carbon dioxide. The book describes these and associated topics. There is an appendix giving some units used in the measurement of photosynthesis, and a bibliography which, although not detailed, lists the hundred or so major papers published in the field. The book is well indexed.

There are, perhaps, one or two general criticisms to be made. The discussion on comparative biochemistry could well have been put near the discussion on mechanism where it seems to fit rather more naturally. In places the text tends to be obscure, but in a small book trying to survey a large field in some detail one cannot expect discursive explanations. There is an inconsistency with current opinion in the section dealing with the enzyme transaldolase. The authors state that it is a four-carbon fragment which is transferred by this enzyme (a three-carbon transfer is normally postulated). This results in an incorrect reconstruction of some details of the metabolic cycle whereby the carbon dioxide acceptor is thought to be regenerated in living tissue, although the overall result is the same.

JEFFREY EDELMAN

Tables of Lagrangian Coefficients for Sexagesimal Interpolation

(*Washington, National Bureau of Standards, 1954, 157 pp., 2.00 dollars*)

A book of tables hardly calls for review in the ordinary sense of the word, but the present book is a timely reminder of two things: the genius of Lagrange and tables as a widespread modern necessity.

To people who have never gone beyond four-figure logarithms it may be a surprise to learn of the tremendous weight and complexity of tables now necessary in science and engineering. (The tables needed for navigation on the high seas, to take a very simple example, weigh pounds and take up a foot or so of shelf room.) The present tables are designed to enable anyone to work out the value of a function of a variable measured in sexagesimal units, such as degrees and minutes and seconds, to eight places of decimals by interpolation, given the value of the function to the nearest degree.

The method depends on an interpolation formula generalised by Joseph Louis Lagrange (1736–1813), born in Italy of French parents. He was a professor at eighteen and the leading mathematician of Europe at twenty-six. He invented the Calculus of Variations, though Euler had worked on the problems involved and generously withheld from publication his own work so that Lagrange should be able to claim priority. This was a matter of appreciation of genius, not of sentiment. Lagrange's own book of analytical mechanics, in which he deduced everything from a few general principles, was described by Hamilton as "a kind of scientific poem". Lagrange was in fact the greatest generaliser who ever lived, and his name will still be used as long as mathematics exists, presumably for ever. It is largely because of Lagrange that the decimal system is now universal and he was responsible for the metric system established in France during the Revolution.

The present book is also a salutary reminder that there are people and institutions spending their time doing the interminable arithmetic that leads to books of tables for people with no claim to mathematical ability to do the most abstruse calculations. Perhaps there will come a time when tables, suitably coded, will form part of the storage content of an electronic computer. Until then printed tables like those in the present book will remain a universal necessity. This one will be welcomed by astronomers, geodesists, engineers and geographers.

C. L. BOLTZ

NEW SCIENTIFIC INSTRUMENTS

This feature is designed to provide information about new scientific instruments which have come on the market. The detailed facts in it are the responsibility of the manufacturers, being taken from literature supplied by the makers. The editor will welcome information from manufacturers about new scientific instruments they are putting on the market. As these notes are intended for the large section of our readership composed of professional scientists, etc., we depart from our customary practice and use symbols and abbreviations to the full in order to be able to convey the maximum amount of detailed information.

Static Eliminator for Precision Balances

In high-precision weighing static charges are a frequent source of error. Stanton Instruments Ltd. have designed a static eliminator consisting of a radioactive source, in a protective mount, that can be permanently fixed inside the balance case. The isotope used remains active for at least three years, and emits only beta-particles which do not penetrate the balance case. Three types are available: Type 1 for front slide operation, Type 2 for side door operation, and Type 3 for combined side door and front slide operation.

When the balance case is closed the flap of this static eliminator opens, and the beam of beta-particles causes the air in the balance case to ionise and the static charges to leak away. The action of the eliminator is practically instantaneous under average laboratory conditions although at very low relative humidity it may take up to 30s to be effective.

Stanton Instruments Ltd., 119 Oxford Street, London, W.1.

Vapour-Phase Chromatograph

Vapour-phase chromatography is a recently developed method of great importance for rapidly analysing and separating small quantities of mixtures of gases or volatile liquids. Good separations can be obtained with many different types of compounds, including hydrocarbons, alcohols, aldehydes and ketones.

The sample to be analysed is injected into the top of a 6-ft. spiral glass column, packed with an inert substance (usually kieselguhr) having an enormous surface area, and impregnated with a suitable non-volatile liquid (usually dinonyl phthalate). A continuous stream of inert gas (usually nitrogen) controlled by needle valves blows the sample along the column. The different components of the mixture pass through the column along with the nitrogen at different rates which depend upon their vapour pressure and their solubility in the dinonyl phthalate. The component which is most volatile and least soluble emerges first, and if the column is sufficiently long the components emerge separated from one another. Their relative concentrations in the nitrogen are indicated by a thermal conductivity cell and recorded as a series of peaks of conductivity as a function of time.

The normal size of liquid sample is only 0·05 ml, and is introduced by hypodermic syringe. Gas samples are introduced by forcing a predetermined amount through a valve. An automatic valve and control are provided for process monitoring work.

For quantitative analysis the instrument must be calibrated with individual components or a synthetic blend. For qualitative analysis there is usually a simple relationship between the time of emergence and the chain length. The Chromatograph requires a maximum power of 1 kW at 250 V, 50 c/s.

Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17.

Courtauld Atomic Models

The Courtauld atomic models based on the designs of Hartley and Robinson (*Trans. Faraday Soc.*, 1952, vol. 48, p. 847; *Disc. Faraday Soc.*, 1954, vol. 16, p. 125) have been designed primarily for research laboratories where accurate models are required. They are also suitable for general educational purposes in schools and universities.

Separate atom models have been devised for each valency arrangement of an element, in most cases by cutting back in the direction of each valency bond, spheres of radii equal to the van der Waals radii obtained from crystallographic data. The scale is 0·8 in. to 1 A. A different colour has been selected for each element to make the distinction between the elements suitable for photography on panchromatic plates. (The colour scheme differs from that recommended by the Institute of Physics.) At present thirty atomic species are available, but others may be produced as experience and demand suggest.

The models are joined by a special arrangement of brass links and rubber collars which provides elastically distortable valency angles. The method of attachment allows large models to be built rapidly and to be handled without falling to pieces; molecules with strained rings may also be built, which is not possible with a rigid linking mechanism. The length of the link used ensures that structures are sufficiently open to observe and measure bond directions and to follow the internal structure of large molecules. The distortion of the bond angles is often a useful measure of the degree of steric hindrance. In cases where there are partial double bonds the standard links may be replaced with special adjustable ones.

Griffin & George Ltd., Kemble Street, Kingsway, London, W.C.2.

Courtauld models for the various isomers of tartaric acid. (*a*) Mesotartaric acid; (*b*) l-tartaric acid; (*c*) d-tartaric acid.

FAR AND NEAR

The Night Sky in November

The constellation Andromeda is now conspicuous, and a very interesting feature in it is the Great Nebula which can be seen with the naked eye on a clear night. To find it, draw an imaginary line through the Pole Star and the centre of the constellation Cassiopeia (which can be easily recognised as it is shaped somewhat like the letter W): produce this line not quite as far as the distance between Polaris and Cassiopeia and it will pass close to Messier 31—the name of the nebula. If there are any doubts about it remember that it lies south on November 1, 15 and 30, at 22h, 21h and 20h, respectively. Its composition is not the same as that of the Great Nebula in Orion, which is merely a great cloud of gas and cosmic dust, but is composed of an immense number of stars—probably 80 thousand million or more—has a diameter of the order of 100,000 light-years. Our own Galaxy—the Milky Way—is similar in dimensions and in the number of stars that it contains. It is believed that some of these spiral nebulae collide during their motions, but collisions between individual stars in them must be rare because they are so far apart, though collisions between the gases in the nebulae take place. It is thought that radio emissions come from these colliding galaxies.

Those who are interested in the observations of the planets will find the following data helpful: Mercury has been excluded as it is not favourably placed for observation.

During the month *Venus* sets about 17h 10m and Mars rises about 4h 20m. On November 1, 15 and 30, Jupiter rises at 00h 15m, 23h 30m and 22h 40m. On the corresponding dates Saturn sets at 17h 20m and rises at 7h 20m and 6h 30m. There is no object in giving the times of setting in the last two cases because these are so near the times of sunset that the planet could not be seen. Jupiter is near the moon on November 8, Mars on November 12, and Venus on November 16.

Radio Signals from Jupiter

Radio signals from Jupiter have been recorded by scientists of Australia's C.S.I.R.O. Division of Radiophysics in Sydney. Mr. P. Wild, a member of the staff of the Division, announced this to an international meeting of radio-astronomers held at Manchester recently.

The radio signals appear to originate from a visible marking on Jupiter. Radio signals from Jupiter were first reported by Burke and Franklin in the U.S.A. earlier this year. Since then the C.S.I.R.O. Division of Radiophysics has discovered signals from Jupiter in records it made in 1950–1 whilst investigating radio noise from the sky. Dr. E. G. Bowen has stated that these earlier signals lasted for a few minutes only and had been thought to be caused by man-made interference (e.g. from the ignition of a passing car) or from local thunderstorms. A new analysis of the earlier records showed that the signals could be associated with a white spot on Jupiter.

Prizes for Science Writing

This year's "Endeavour" prizes for scientific essays have been awarded to the following: A. N. Glazer, D. Hull, and Miss I. A. Daves. The two junior prizewinners are J. F. Ross of Fleet and P. I. Vardy of Ashton.

Research, the monthly journal published by Butterworths, has awarded three essay prizes. Both the £100 first prize and the £50 prize for the best script submitted by a scientist of under 30 to go to Dr. F. Peter Woodford of Leeds University. The second prize (£50) has been won by Dr. Edmund C. Potter, Chief Engineer's Research Branch, Central Electricity Authority.

Recruitment of Patent Examiners

Our note about the shortage of patent examiners (August issue, p. 354) incorrectly referred to the competitive entrance examination. Today there is no entrance to the Patent Office by written examination. Since the end of 1951 Assistant Examiners have been recruited as a result of appearance before Civil Service Commission selection boards, following the simple completion of an application form by means of which a candidate with a First or Second Class Honours degree (or its equivalent) in certain scientific subjects may apply for an established appointment. He can apply on the one form to be considered for a post as Scientific Officer or as Patent Examiner or for both. Furthermore a candidate sitting for his final degree examination at any time during the year may make an application to the Civil Service Commission before the result of the examination is known, although he cannot be appointed as an Assistant Examiner unless he does succeed in obtaining his degree. A few similar posts exist in the Ministry of Supply. Details of salary, etc. can be found in this month's advertisement columns (see "Official Appointments").

Independent Television

The Independent Television Authority, whose programme was seen by nearly a million viewers in the London and Home Counties on September 22, expects to be able to provide a national coverage within two years. A station at Lichfield (near Sutton Coldfield) will be operating by February 1956, and further stations are planned for the Manchester and Yorkshire areas. The present difficulty is one of channel allocation within the frequency band allotted to television, but it is expected that this difficulty will be overcome by the time the north-country stations are ready for construction.

It should be noted that the Authority is not responsible for the actual programme material, which is being handled by two companies: Associated-Rediffusion Ltd. for Monday–Friday programmes, and Associated Broadcasting Company for week-ends in the London area. Associated-Rediffusion have recently opened a studio centre at Wembley at a cost of £650,000, equipped with special control systems for split-second timing of commercial announcements and sponsored programmes. The importance of accurate timing will be appreciated by mentioning the charges for advertising: £600 for 2 minutes in the popular viewing hours, and £1050 for 5 minutes.

Reception of the transmissions in the home counties generally exceeded expectations, and areas as far away from Croydon as Chelmsford, Thorpe Bay and Aylesbury reported very good results. One of the troubles of ultra-short wave television is the ghost images produced by reflexion from neighbouring buildings, and in most cases a form of directional aerial has to be installed to minimise this effect.

Manufacturers of television receivers state that, with few exceptions, it is not possible to convert receivers to the new wavelength if they are over five years old, and some difficulty may be experienced in areas close to the B.B.C. television transmitters. The present I.T.A. transmitter at Croydon will be transferred to the Crystal Palace site in a year's time, and the power will be increased to 200 kilowatts.

For the record, the honour of being the first advertiser to appear on British television went to Gibbs, the proprietors of S.R. toothpaste, the winners of the ballot for announcements on the opening night. The quality of the advertising which appears is rigidly controlled by the rules issued by the Advertising Advisory Committee appointed by the Authority under the Television Act, 1954. Among the many prohibitions are any methods of advertising which may result in mental, physical, or moral harm to children, and, in fact, any advertisement which may encourage children to be a nuisance is barred!

The general opinion of experienced viewers is that the new rival television, once over its teething troubles, will provide the necessary stimulus to the B.B.C. to extend and improve its own service, and the licence-holder will benefit accordingly.

Institute of Biology's New Address

The Institute of Biology has moved to new premises, and its address is now 41 Queen's Gate, London, S.W.7.

Index of British Scientific Research

Scientific Research in British Universities 1954–5 has just been published by H.M.S.O., price 12*s.* 6*d.* As in previous issues the entries are arranged in alphabetical order of universities. A name-index is included so that the work being done by any particular research worker can be found, and a subject-index indicates where particular programmes of research are being carried out.

B.B.C. starts Colour TV Test Transmissions

The B.B.C. is starting experimental colour TV transmissions. This step follows the delivery by Marconi's Wireless Telegraph Co. Ltd. of a complete colour television camera chain which fulfils the first order the Corporation has given for colour television camera equipment, and will provide an all-electronic compatible system to anglicised N.T.S.C. standards.

An Insect Film in Colour

The insects ravage man's crops and pillage his granaries. They transmit many terrible diseases; mosquito-borne malaria, for instance, affects a sixth of the human race, while the disease-carrying tsetse fly denies man the use of 4 million square miles of land in Africa. Facts such as these are brought home with great force by the latest film made by the Shell Film Unit. This brilliant colour film, *The Rival World*, was directed by Bert Haanstra and photographed by three cameramen—Sidney Beadle, Ronald Whitehouse, and Han Van Gelder.

To cover the subject of insect-control, the film unit spent two and a half months in East Africa, the Sudan, and Egypt, and used material taken on location in other tropical countries. Many difficulties were met during the shooting of the locust-control sequences, where close contact was maintained with the Desert Locust Controls of East Africa and the Sudan to trace the movements of hopper bands and flying swarms. To get vital shots, reports of bands and swarms had to be followed up by rapid travelling over long distances through the roughest country: notice was short—a locust attack on a maize crop sent the unit and equipment 60 miles at two hours' warning. There were exciting moments flying with the spraying aircraft through swarms when the impact of the locusts on the windscreens obscured all vision: all this is vividly, almost horrifyingly, recorded in the finished film.

Centenary of Mauve

The discovery of the first synthetic dye—William Perkin's mauve—was made in 1856, and next year centenary celebrations are to be held in London.

The initial move was made by the Society of Dyers and Colourists, which has now been joined by The Royal Society, The Chemical Society, The Society of Chemical Industry, The Royal Institute of Chemistry and The Association of British Chemical Manufacturers. An organising committee has been set up under the chairmanship of Sir Robert Robinson. Detailed plans have not yet been formulated but an appeal will shortly be made for support for a £100,000 fund which will be used mainly to set up a trust fund for financing Perkin Centenary Scholarships.

LETTER TO THE EDITOR

Relativity and the Order of Events

Sir:

The letter of Dr. M. A. Phillips (August issue, p. 350), being itself incorrect, only adds to the confusion already caused by the misleading statement in Chapman Pincher's article about Einstein.

According to the Special Theory of Relativity it *is* possible for certain events to appear in a different order to two different observers, but only those events which occur so far apart in space or so close together in time (as judged by any one observer) that they could not be causally connected even by light—the fastest causal impulse known.

This can be seen at once from the equation quoted by Dr. Phillips:

$$t' = \frac{t - vx/c^2}{(1 - v^2/c^2)^{\frac{1}{2}}},$$

where t', t and x refer to time and space *differences* between the events. It is not so difficult to make t' negative (for positive t) as Dr. Phillips suggests; indeed the condition can be seen at a glance to be:

$$\frac{vx}{c^2} > t.$$

Since $v < c$ is axiomatic in this context, an order reversal is impossible unless:

$$x > ct.$$

But x being the *minimum* distance between the events, as judged by the first observer, it follows that not even light, which travels at speed c, could connect events which obey this condition for order reversal.

The Special Theory of Relativity, in fact, does not allow cause and effect to be reversed, though causally isolated events may be. Readers would still be wasting time in waiting for the kettle to boil before lighting the gas.

Yours sincerely,

M. S. Smith, M.A. (Cantab).

(Physics Dept., King's College School, Wimbledon.)

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